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OF TEXAS AT AUSTIN(U) TEXAS UNIV AT AUSTIN ELECTRONICS
RESEARCH CENTER E J POWERS 15 MAY 85 F49620-82-C-0033

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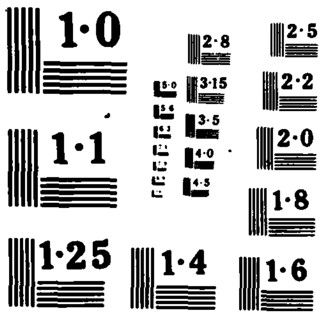
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Annual Report on Electronics Research

at The University of Texas at Austin

No. 32

For the period April 1, 1984 through March 31 1985

JOINT SERVICES ELECTRONICS PROGRAM

Research Contract AFOSR F49620-82-C-0033

May 15, 1985

Bureau of Engineering Research
The University of Texas at Austin
Austin, Texas 78712

The Electronics Research Center at The University of Texas at Austin consists of interdisciplinary laboratories in which graduate faculty members, Master and PhD candidates from numerous academic disciplines conduct research. The disciplines represented in this report include information electronics, solid state electronics, quantum electronics, and electromagnetics.

The research summarized in this report was supported by the Department of Defense's JOINT SERVICES ELECTRONICS PROGRAM (U.S. Army, U.S. Navy, and the U.S. Air Force) through the Research Contract AFOSR F49620-82-C-0033. This program is monitored by the Department of Defense's JSEP Technical Coordinating Committee consisting of representatives from the U.S. Army Research Office, Office of Naval Research and the U.S. Air Force Office of Scientific Research.

Annual Report on Electronics Research at The University of Texas at Austin

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Submitted by Edward J. Powers
on Behalf of the Faculty and Staff
of the Electronics Research Center

May 15, 1985

ELECTRONICS RESEARCH CENTER

Bureau of Engineering Research
The University of Texas at Austin
Austin, Texas 78712

ABSTRACT

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear detection and estimation, (2) electronic time-variant signal processing, and (3) digital time series analysis with applications to nonlinear wave phenomena.

In the Solid State Electronics area recent findings in (1) solid state interface reactions and instabilities, (2) electronic properties and structure of metal silicides and interfaces, and (3) implantation and interface properties of InP and related compounds are described.

In the Quantum Electronics area progress is presented for the following projects: (1) quantum effects in laser induced damage, (2) nonlinear Raman scattering from molecular ions and (3) nonlinear optical interactions.

In the Electromagnetics area progress in guided waves in composite structures is summarized.

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PERSONNEL AND RESEARCH AREAS

ELECTRONICS RESEARCH CENTER

Phone: (512) 471-3954

Administration for the Joint Services Electronics Program

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Professor Rodger M. Walser, Assoc. Director

Electronics Research Center Staff

Connie Finger, Administrative Assistant I
Jan White, Accountant I

Coordinators For Research Areas

Professor S.I. Marcus, Information Electronics
Professor R.M. Walser, Solid State Electronics
Professor M.F. Becker, Quantum Electronics
Professor T. Itoh, Electromagnetics

Faculty

Information Electronics:

J.K. Aggarwal, Professor, ECE, 471-1369
S.I. Marcus, Professor, ECE, 471-3265
E.J. Powers, Professor, ECE, 471-1430
J.L. Speyer, Professor, Aerospace, 471-4258

Solid State Electronics:

M.F. Becker, Associate Professor, ECE, 471-3628
R.W. Bene', Professor, ECE, 471-1225
J.L. Erskine, Associate Professor, Physics, 471-1464
B.G. Streetman, Professor, ECE, 471-1754
R.M. Walser, Professor, ECE, 471-5733

Quantum Electronics:

M.F. Becker, Associate Professor, ECE, 471-3628
M. Fink, Professor, Physics, 471-5747
J. Keto, Associate Professor, Physics, 471-4151
H.J. Kimble, Assistant Professor, Physics, 471-1668
R.M. Walser, Professor, ECE, 471-5733

PERSONNEL AND RESEARCH AREAS

Electromagnetics

T. Itoh, Professor, ECE, 471-1072

Postdoctoral Research Associates and Fellow

Marshall Onellion, Physics, Postdoctoral Research Associate
Christoph Ritz, ECE, Fellow
Albert T. Rosenberger, Physics, Postdoctoral Research Associate

Research Assistants

Norbert Boewering, Physics
Robert Brecha, Physics
Dan Coffman, Physics
Joe Comunale, Physics
*H. Ehsani, ECE
*C. Farley, ECE
*Steven Fry, ECE
*C.C. Han, ECE
*John Hartley, Physics
Austin Huang, ECE
Yong Jee, ECE
Kyoung Il Kim, ECE
Tae S. Kim, ECE
Taiho Koh, ECE
*Y.H. Ku, ECE
Tzong-Yeu Leou, ECE
*S. Lester, ECE
Bih Wah Lin, ECE
Jorge Castro Luengo, Physics
Richard Mawhorter, Physics
*L.A. Orozco, Physics
Seguen Park, ECE
*Won Woo Park, ECE
*Andy Ross, Physics
*H. Shin, ECE
Nag Un Song, ECE
Ching-Kuang Tzuang, ECE
*Evan K. Westwood, ECE
*Cheryl White, Physics
John White, Aerospace
*L.A. Wu, Physics
Hwa-Yueh, Yang, ECE

*Denotes persons who have contributed to JSEP projects, but who have not been paid out of JSEP funds (e.g., students on fellowships).

PERSONNEL AND RESEARCH AREAS

Advanced Degrees Awarded

Nam-In Cho, ECE, M.S., May 1984, "Noise Properties of Ultrathin Nickel Films on Single Crystal Silicon."

DooWhan Choi, ECE, Ph.D., May 1984, "Engineering Applications of Higher-Order Spectra."

Dan Coffman, Physics, M.S., December 1984, "Electron-Atom Shadow Scattering/ Does It Exist or Not?"

C.W. Farley, ECE, M.S., December 1984, "The Activation and Migration of Impurities in Ion Implanted Semiconductors".

Y. Fukuoka, ECE, Ph.D., May 1984, "Guided Wave Phenomena in Device Structures Containing Semiconductor Materials."

Fawzi Hadjarab, Physics, M.S., May 1984, "Imaging Properties of the Spherical Analyzer."

Y.K. Jhee, ECE, Ph.D., May 1984, "Charge Emission and Precursor Accumulation in the Multiple-Pulse Damage Regime of Silicon."

Maxine McBrinn-Howard, Physics, M.S., August 1984, "Construction of a Supersonic Beam Apparatus."

R. Mezenner, ECE, M.S., August 1984, "Encapsulation and Annealing of GaAs and InP."

S. Park, ECE, Ph.D., May 1984, "On Time-Variant Digital Signal Processing: Synthesis and Implementation."

H. Shin, ECE, M.S., December 1984, "Thermal Annealing Studies of Nitride Encapsulant on GaAs."

R.L. Strong, Physics, Ph.D., August 1984, "Adsorbate Structure Determination Using High-Resolution Electron Energy Loss Spectroscopy and Lattice Dynamical Calculations."

S.W. Yung, ECE, Ph.D., May 1984, "A Study of Distributed Millimeter-Wave Isolators."

Q. Zhang, ECE, M.S., May 1984, "Analysis of a Suspended Patch Antenna Excited by an Inverted Microstrip Feed."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

JOURNAL ARTICLES

* A.M. Turner and J.L. Erskine, "Surface Electronic Properties of Fe(100)," Phys. Rev. B30 (1984).

R.L. Strong and J.L. Erskine, "A New Lens System for Surface Vibrational Spectroscopy at High Impact Energies," Rev. of Sci. Instruments 55, 1304 (1984).

* J.L. Erskine and Yu-Jeng Chang, "Selective Growth, Diffusion Layers, and the Schottky Barrier Height in Nickel Silicide-Silicon Interfaces," Mat. Res. Soc. Proc. 25, 353 (1984).

A.M. Turner, A.W. Donoho and J.L. Erskine, "Experimental Bulk Electronic Properties of Ferromagnetic Iron," Phys. Rev. B29, 2986 (1984).

H.J. Kimble and L. Mandel, "Photoelectric Detection of Polychromatic Light," Phys. Rev. A30, 844 (1984).

* L.A. Orozco, A.T. Rosenberger, and H.J. Kimble, "Intrinsic Dynamical Instability in Optical Bistability with Two-Level Atoms," Phys. Rev. Lett. 53, 2547 (1984).

J.L. Speyer, D.G. Hull, C.Y. Tseng and S.W. Larson, "Estimation Enhancement by Trajectory Modulation for Homing Missiles," AIAA Journal of Guidance, Control, and Dynamics, Vol. 7, No. 2 (March-April 1984).

D.G. Hull, W.M. Greenwell, and J.L. Speyer, "Adaptive Noise Estimation for Homing Missiles," AIAA Journal of Guidance, Control and Dynamics, Vol. 7, No. 3 (May-June 1984).

S.J. Levinson, J.M. Beall, E.J. Powers and Roger D. Bengtson, "Space-Time Statistics of the Turbulence in a Tokamak Edge Plasma," Nuclear Fusion, Vol. 24, No. 5, 527-539 (May 1984).

* S. Park and J.K. Aggarwal, "A Simple Form Synthesis of Linear Time-Variant Digital Filters via Spectral Decomposition of its Impulse Response," Journal of the Franklin Institute, Vol. 318, No. 3, pp. 151-164 (September 1984).

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

D.A. Kohl, P. Pulay and M. Fink, "On the Calculations of Electron Scattering Cross Sections from Molecular Wavefunctions," Theo. Chem., 108, pp. 149-159 (1984).

Shang-De Xie, M. Fink and D.A. Kohl, "Basis Set Dependence of Ab Initio SCF Elastic Born Scattering Cross Sections for Electrons on C_2H_4," J. Chem. Phys. 81, pp. 1940-1942 (1984).

*Y.K. Jhee, M.F. Becker, and R.M. Walser, "Charge Emission and Accumulation in Multiple Pulse Damage of Silicon," Proc. of Laser Induced Damage in Optical Materials - NBS publ. (1984).

T.D. Raymond, N. Bowering, Chien-Yu Kuo, and J.W. Keto, "Two-Photon Laser Spectroscopy of Xenon Collision Pairs," Phys. Rev. A29, pp. 721-734 (1984).

N. Bowering, T.D. Raymond and J.W. Keto, "Enhanced Quenching at Reduced Internuclear Separations of Xenon Collision Pairs," Phys. Rev. Lett. 52, pp. 1880-1883 (1984).

T. D. Raymond, Shawn T. Walsh and John W. Keto, "Narrowband Dye Laser with a Large Scan Range," Appl. Optics 23, pp. 2062-2064 (1984).

B.G. Streetman, "Solid State Electronic Devices," Collier's Encyclopedia (New York: MacMillan Publishing Co.), pp. 180-191 (1984).

*O. Hernandez-Lerma and S. I. Marcus, "Optimal Adaptive Control of Priority Assignment in Queueing Systems," Systems and Control Letters, Vol. 4, pp. 65-72 (April 1984).

*C.W. Farley and B.G. Streetman, "Simulation of Anomalous Be Diffusion in Semi-Insulating InP," J. Electrochem. Soc. 131, pp. 946-947 (April 1984).

*S.K. Banerjee, B. Lee, J.E. Baker, D.A. Reed and B. G. Streetman, "Annealing of Ion-Implanted Silicon-on-Insulator Films Using a Scanned Graphite Strip Heater," Thin Solid Films 115, pp. 19-26 (May 1984).

*O. Hernandez-Lerma and S. I. Marcus, "Identification and Approximation of Queueing Systems," IEEE Trans. Automatic Control, Vol. AC-29, pp. 472-474 (May 1984).

S.W. Yun and T. Itoh, "A Distributed Millimeter-Wave Isolator Using Nonreciprocal Coupling Structure," International J. Infrared and Millimeter Waves, Vol. 5, No. 6, pp. 775-792 (June 1984).

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

* Y. Fukuoka and T. Itoh, "Coplanar Schottky Variable Phase Shifter Constructed on GaAs Substrate for Millimeter-Wave Applications," International J. Infrared and Millimeter Waves, Vol. 5, No. 6, pp. 793-801 (June 1984).

* T.Y. Leou and J.K. Aggarwal, "Recursive Implementation of LTV Filters - Frozen-Time Transfer Function vs. Generalized Transfer Function," IEEE Proceedings, Vol. 72, No. 7, pp. 980-981 (July 1984).

* J.L. Speyer and J.E. White, "The Shiryayev Sequential Probability Ratio Test for Redundancy Management," AIAA Journal of Guidance, Control, and Dynamics (September-October 1984).

K.D. Stephan and T. Itoh, "Inexpensive Short-Range Microwave Telemetry Transponder," Electronics Letters, Vol. 20, No. 21, pp. 877-878 (October 11, 1984).

S.I. Marcus, "Algebraic and Geometric Methods in Nonlinear Filtering," SIAM J. Control and Optimization, Vol. 22, pp. 817-844 (November 1984).

J.W. Grizzle and S. I. Marcus, "Optimal Control of Systems Possessing Symmetries," IEEE Trans. Automatic Control, Vol. AC-29, pp. 1037-1040 (November 1984).

J.L. Speyer, J.E. White, R.K. Douglas and D.G. Hull, "MIMO Controller Design for Longitudinal Decoupled Aircraft Motion," AIAA Journal of Guidance, Control and Dynamics, Vol. 7, No. 6 (Nov.-Dec. 1984).

L.Q. Bui, D. Ball and T. Itoh, "Broadband Millimeter-Wave E-Plane Bandpass Filters," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-32, No. 12, pp. 1655-1658 (December 1984).

* R. Sorrentino and T. Itoh, "Transverse Resonance Analysis of Finline Discontinuities," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-32, No. 12, pp. 1633-1638 (December 1984).

R.J. Cook and H.J. Kimble, "Possible Direct Observation of Quantum Jumps," Phys. Rev. Lett. 54, 1023 (1985).

H.J. Kimble, A. Mezzacappa, and P.W. Milonni, "Time Dependence of Photon Correlations in a Three-Level Atomic Cascade," Phys. Rev. A, (1985).

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

R.L. Strong and J.L. Erskine, "Adsorbate Structure Determination Using Surface Vibrational Spectroscopy" Phys. Rev. Lett. 54, 346 (1985).

Jabez J. McClelland and M. Fink, "Correlation Effects in Neon Studied by Elastic and Inelastic High Energy Scattering," Phys. Rev. A, 31, pp. 1328-1335 (1985).

* S.N. Ketkar and M. Fink, "The Structure of Dichromium Tetraacetate by Gas Phase Electron Diffraction, JACS 107, pp. 338-340 (1985).

B.G. Streetman, "Semiconductors and Transistors," Chapter 18 in Reference Data for Radio Engineers, 7th Edition (Indianapolis: Howard W. Sams & Co.) (1985).

J.L. Speyer, D. Dannemiller, and D. Walter, "Periodic Optimal Cruise of an Atmospheric Vehicle," AIAA Journal of Guidance, Control, and Dynamics, Vol. 8, No. 1 (Jan.-Feb. 1985).

* J.W. Grizzle and S.I. Marcus, "The Structure of Nonlinear Control Systems Possessing Symmetries," in IEEE Trans. Automatic Control, Vol. AC-30, pp. 248-258 (March 1985).

* S. Park and J.K. Aggarwal, "Recursive Synthesis of Linear Time-Variant Digital Filters via Chebyshev Approximation," IEEE Transactions on Circuits and Systems, Vol. CAS-32, No. 3, pp. 245-251 (March 1985).

* Y. Fukuoka and T. Itoh, "Field Analysis of a Millimeter-Wave GaAs Double-Drift IMPATT Diode in the Traveling-Wave Mode," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-33, No. 3, pp. 216-222 (March 1985).

T.S. Chu and T. Itoh, "Modified Residue Calculus Technique for Microstrip Discontinuities," Electronics Letters, Vol. 21, No. 7, pp. 257-258 (March 28, 1985).

* T.L. Song and J.L. Speyer, "The Modified Gain Extended Kalman Filter and Parameter Identification in Linear Systems," to appear in Automatica.

D.G. Hull, C. Y. Tsang and J.L. Speyer, "Maximum Information Guidance for Homing Missiles," to appear in the AIAA Journal of Guidance, Control and Dynamics.

M.A. Thompson and J.L. Erskine, "Electronic Properties of p(1x1) Ni Films on Cu(100)", Phys. Rev. B, in press.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

R.L. Strong and J.L. Erskine, "Underlayer Formation by Oxygen on Al(111) and Ti(0001)", J. Vac. Sci. Technol., in press.

Bruce R. Miller and M. Fink, "The Vibrationally Averaged Temperature Dependent Structure of Polyatomic Molecules III. N_2O", J. Chem. Phys., in press.

F. Hadjarab and J.L. Erskine, "Image Properties of the Hemispherical Analyzer Applied to Multichannel Energy Detection," J. Electron. Spect. Rel. Phen., in press.

D.-W. Choi, R.W. Miksad, E.J. Powers and F.J. Fischer, "Application of Digital Cross-Bispectral Analysis Techniques to Model the Nonlinear Response of a Moored Vessel System in Random Seas," Journal of Sound and Vibration, in press.

R.L. Strong and J.L. Erskine, "A Simple Lattice Dynamical Slab Model for Interpreting Surface Vibrational Spectra: Application to Oxygen on Ni(100) and Ni(111)", Phys. Rev. B, in press.

J.J. McClelland and M. Fink, "Electron Correlation and Binding Effects in Measured Electron Scattering Cross Sections of CO_2", Phys. Rev. Lett, accepted.

R.W. Bene', G.S. Lee and N.I. Cho, "1/F Noise in Ultrathin Co and Ni Films on Si Substrates," accepted for publication in Thin Solid Films.

*Y.K. Jhee, M.F. Becker and R.M. Walser, "Charge Emission and Precursor Accumulation in the Multiple Pulse Damage of Silicon," accepted for publication by the Journal of the Optical Society of America, Part B.

*T. Koh and E.J. Powers, "Second-Order Volterra Filtering and Its Application to Nonlinear System Identification," accepted for publication in IEEE Transactions on Acoustics, Speech, and Signal Processing.

*T. Koh, and E.J. Powers, "Efficient Methods to Estimate Correlation Functions of Gaussian Processes and Their Performance Analysis," accepted for publication in IEEE Transactions on Acoustics, Speech, and Signal Processing.

*M. Onellion and J.L. Erskine, "Experimental Observation of Adsorbate Orbital Splitting at Single Crystal Metal Surfaces," Phys. Rev. B, to be published.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

* Y.H. Ku and R.W. Bene', "Stress in Ultrathin Cobalt Films on Silicon," submitted to J. Applied Physics.

J.P. Woods and J.L. Erskine, "Experimental Investigation of B,H on W(100) Using High Resolution Electron Energy Loss Spectroscoy: Bond Distances, Scattering Mechanisms and Impact Scattering Selection Rules," Phys. Rev. Letters, submitted.

N. Bowering, M.R. Bruce, and J.W. Keto, "Collisional Deactivation of Two-Photon Laser Excited Xenon $5p^5 6p$. II. Lifetimes and Total Quench Rates," submitted to J. Chem. Phys.

* M. Onellion and J.L. Erskine, "Rare Gas Physisorption on NiAl(110): Local Work Function Studies," to be submitted to Phys. Rev. B.

* R.W. Bene' and H. Ehsani, "TED Studies of Ultrathin Pd Films on GaAs Substrates," in preparation.

Jacek Borysow, Hossain Golnabi, Lothar Frommhold and J.W. Keto, "Novel Technique for Measuring Raman Gain of Pulsed Lasers," in preparation.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

TECHNICAL PRESENTATIONS

Texas Instruments
Dallas, Texas
April 1984

*R.W. Bene', "The Systematics of Metal-Compound Semiconductor Interfacial Reaction in the Solid State."

University of Texas at Austin
Physics Department
Austin, Texas
April 4, 1984

*John W. Keto, "Dynamics of Multiphoton Excited Atoms."

Distinguished Lecturer Series
Department of Electrical Engineering
University of Houston
Houston, Texas
April 9, 1984

*S.I. Marcus, "Recent Developments in Nonlinear Estimation Theory."

General Motors Research Laboratory
Warren, Michigan
April 23, 1984

E.J. Powers, "Applications of Digital Time Series Analysis."

American Vacuum Society Lecture
Texas A&M University
College Station, Texas
April 24, 1984

J.L. Erskine, "Surface Vibrational Spectroscopy of Ordered Overlayers on Crystal Surfaces."

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

SPIE Technical Symposium East '84
Arlington, VA.
April 29-May 4, 1984

* T. Itoh, "Recent Development of Dielectric Waveguide Technology."

1st Annual Research Review
Dept. of Electrical Engineering
University of Texas at Austin
Austin, Texas
May 1984

* R.W. Bene', "Systematics of Interface Solid State Reactions."

Electrophysics Seminar
University of Maryland
College Park, Maryland
May 4, 1984

* T. Itoh, "Dielectric Waveguide Technology for Microwave and Millimeter-Wave Applications."

107th Meeting of the
Acoustical Society of America
Norfolk, Virginia
May 6-10, 1984

E.J. Powers, D. Choi, J-H. Chang and R.O. Stearman, "Bispectral Analysis of Parametric and Nonlinear Phenomena."

1984 International Symposium on
Circuits and Systems
Montreal, Canada
May 7-10, 1984

* S.H. Park and J.K. Aggarwal, "Recursive Synthesis of Linear Time-Variant Digital Filters."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

16th Annual Offshore Technology Conference
Houston, Texas
May 7-9, 1984

T. Koh, E.J. Powers, R.W. Miksad and F.J. Fischer, "Applications of Nonlinear Digital Filters to Modeling Low-Frequency, Nonlinear Drift Oscillations of Moored Vessels in Random Seas."

1984 IEEE International Conference on Plasma Science
St. Louis, Missouri
May 14-16, 1984

S.B. Kim, Y.P. Kochanski, J. Snipes and E.J. Powers, "Characteristics of Double Sawteeth and Sawtooth-Like Oscillations on TEXT."

S.J. Levinson, E.J. Powers, Ch.P. Ritz and Roger D. Bengtson, "Space-Time Statistics and Particle Transport."

Ch.P. Ritz, S.J. Levinson, E.J. Powers and R.D. Bengtson, "Wave-Wave Coupling and Energy Flow in a Tokamak Edge Plasma."

Users Group
Austin, Texas
May 23, 1984

R.L. Strong and J.L. Erskine, "Use of Electron Energy Loss Spectroscopy to Determine Positions of Adsorbates."

Phillips Petroleum Company
Bartlesville, OK
May 24, 1984

E.J. Powers, "Applications of Digital Time Series Analysis to Nonlinear Wave Phenomena."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

1984 IEEE MTT-S International
Microwave Symposium
San Francisco, CA
May 30-June 1, 1984

L.Q. Bui, D. Ball and T. Itoh, "Broadband Millimeter-Wave E-Plane Bandpass Filters."

* R. Sorrentino and T. Itoh, "Transverse Resonance Analysis of Finline Discontinuities."

* Y. Fukuoka and T. Itoh, "Field Analysis of Millimeter-Wave GaAs Double-Drift IMPATT Diode in the Travelling-Wave Mode."

Conference on Lasers and Electro-Optics
Anaheim, CA
June 20, 1984

* K.-C. Peng, L.-A. Wu and H.J. Kimble, "Frequency-Stabilized Nd^{+3}: YAG Laser."

Optical Society of America
Topical Meeting on Ultrafast Phenomena
Monterey, CA
June 1984

* M.F. Becker and Y.K. Jhee, "Subthreshold Picosecond Laser Damage in Silicon Associated with Charge Emission."

American Vacuum Society Meeting
Dallas, Texas
June 4, 1984

B.G. Streetman, "Thin Film Processes and Characterization Tools."

Colloquia
University of Kaiserslautern
Germany
June 20, 1984

M. Fink, "Studies of the Metal-Metal by Gas Phase Electron Diffraction."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Thirteenth International Quantum Electronics Conference
Anaheim, CA
June 21, 1984

* A.T. Rosenberger, L.A. Orozco, and H.J. Kimble, "Observation of the Single-Mode Instability in Optical Bistability."

International IEEE VLSI
Multilevel Interconnection Conference
New Orleans, LA
June 21-22, 1984

Y. Fukuoka, Q. Zhang, D. Neikirk and T. Itoh, "Analysis of Multilayer Interconnection Lines for a High Speed Digital Integrated Circuit."

1984 IEEE AP-S Symposium/
National Radio Science Meeting
Boston, MA.
June 25-28, 1984

* T. Itoh, "CAD-Oriented Field and Network Analysis - Overview."

U.S. Army Harry Diamond Laboratory
Adelphi, MD
June 27, 1984

* T. Itoh, "Microwave Research at University of Texas."

International Conference on
Plasma Physics
Lausanne, Switzerland
June 27-July 4, 1984

Ch.P. Ritz, S.J. Levinson, E.J. Powers and R.D. Bengtson, "Turbulence and Energy Cascading in the Edge Plasma of the TEXT Tokamak."

Chelsea College
University of London
London, England
July 1984

R.W. Bene', "1/F Noise in Thin Film Systems."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Korean Science and Technology Symposium
Seoul, Korea
July 2-6, 1984

* J.Y. Hong and E.J. Powers, "Nonlinear Radar Systems Based on Digital Higher-Order Spectral Techniques."

International Union of Theoretical
and Applied Mechanics Second Symposium
on Laminar-Turbulent Transition
Novosibirsk, USSR
July 9-13, 1984

F.L. Jones, R.W. Miksad and E.J. Powers, "Wave Modulations and Nonlinear Interactions During Transition to Turbulence of a Wake."

Colloquia
University of Wurzburg
Germany
July 12, 1984

M. Fink, "Studies of the Metal-Metal by Gas Phase Electron Diffraction."

Sandia National Labs
Albuquerque, New Mexico
August 1984

J.L. Speyer, "Guidance Law Synthesis for Hypersonic Gliders."

UCLA Short Course
Los Angeles, CA
August 15, 1984

T. Itoh, "Generalized Scattering Parameter Methods."

XVIth International Congress of
Theoretical and Applied Mechanics
Lyngby, Denmark
August 19-25, 1984

R.W. Miksad, F.L. Jones, and E.J. Powers, "The Generation of Low-Frequency Fluctuations by Nonliner Interactions During Transition to Turbulence."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

XXIst General Assembly of URSI
Florence, Italy
August 28-September 5, 1984

*T. Itoh, "Survey of New Waveguides."

*T. Itoh, "Fin-Line and E-Plane Structures for Millimeter Wave Circuits."

International Conference on
Digital Signal Processing
Florence, Italy
September 5-8, 1984

*L. Khadra, E.J. Powers and Y.C. Kim, "Digital Complex Demodulation of Nonstationary Time Series."

Technische Hochschule Aachen
Aachen, W. Germany
September 7, 1984

*T. Itoh, "Millimeter-Wave Research at University of Texas."

14th European Microwave Conference
Liege, Belgium
September 10-13, 1984

S.W. Yun and T. Itoh, "Nonreciprocal Wave Propagation in a Hollow Image Guide with a Ferrite Layer."

14th European Microwave Conference
Liege, Belgium
September 10-13, 1984

Q. Zhang, Y. Fukuoka, T. Itoh and L. Su, "Analysis of a Suspended Patch Antenna Excited by an Electromagnetically Coupled Inverted Microstrip Feed."

AFOSR Workshop on Metastable Helium
AFRPL, Edwards Air Force Base
Pasadena, California
September 4, 1984

J.W. Keto, "Optical Pumping of $He_2 a^3E$ in Liquid Helium."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Tenth International Conference on
Plasma Physics and Controlled Nuclear Fusion Research
International Atomic Energy Agency
London, U.K.
September 12-19, 1984

D.L. Brower, ..., E.J. Powers, et al., "Tokamaks-Description of Turbulence and the First Test of an Ergodic Magnetic Limiter."

Fern Universitat Hagen
Iserlohn, W. Germany
September 13, 1984

*T. Itoh, "Millimeter-Wave Research at University of Texas."

Technische Universitat Braunschweig
Braunschweig, W. Germany
September 13, 1984

*T. Itoh, "Millimeter-wave Research at University of Texas."

Technische Universitat Hamburg
Hamburg, W. Germany
September 14, 1984

*T. Itoh, "Millimeter-wave Research at The University of Texas."

North Jersey IEEE MTT-AP
Chapter Meeting
Nutley, NJ
September 18, 1984

*T. Itoh, "Transmission Lines for Microwave and Millimeter-Wave Circuits."

Seminar
RCA David Sarnoff Research Center
Princeton, NJ
September 19, 1984

*T. Itoh, "Microwave and Millimeter-Wave Research at The University of Texas."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Seminar
NASA Lewis Research Center
Cleveland, OH
September 24, 1984

T. Itoh, "Microwave Transmission Structures."

Atomic and Molecular Seminar
Physics Department
University of Texas at Austin
Austin, Texas
September 28, 1984

* J.W. Keto and Roger Taylor, "Stimulated Raman Gain Spectroscopy and the Search for Sensitivity."

Sandia National Laboratories
Albuquerque, NM
October 1984

* M.F. Becker, "Charge Emission and Accumulation of Damage for Multi-Pulse Laser Irradiation of Silicon."

16th ASTM Laser Damage Symposium
Boulder, Co
October 1984

* M.F. Becker, "Charge Emission and Accumulation in Multiple-Pulse Damage of Silicon."

16th ASTM Laser Damage Symposium
Boulder, CO
October 1984

* M.F. Becker, "Surface Potential as a Laser Damage Diagnostic."

Invited Talk
Research and Development Center
Grumman Aerospace Corp.
Bethpage, NY
October 9, 1984

R.M. Walser, "Thin Film Magretodielectrics."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Seminar
University of Colorado
Boulder, Colorado
October 19, 1984

* H.J. Kimble, "Optical Bistability with Two-Level Atoms."

1984 International Symposium on
Noise and Clutter Rejection in
Radars & Imaging Sensors
Tokyo, Japan
October 22-24, 1984

* J.Y. Hong and E.J. Powers, "Simulation Study of Detection of Nonlinear Metallic Targets in Sea Clutter-Type Noise."

9th International Conference on
Infrared and Millimeter Waves
Takarazuka, Japan
October 22-26, 1984

* Y. Fukuoka and T. Itoh, "Travelling-Wave Characteristics of Millimeter-Wave IMPATT Diode."

S.W. Yun and T. Itoh, "Bias Dependence of a Hollow Image Guide Type Isolator."

Invited Talk
Southeastern Section of American Physical Society
Memphis, Tennessee
October 26, 1984

* H.J. Kimble, "Optical Bistability and Dynamical Instability Using Two-Level Atoms."

Tokyo Chapter of IEEE
MTT-S Meeting
Uniden Corporation
Ichikawa, Japan
October 29, 1984

* T. Itoh, "Recent Trends in Millimeter-Wave Research."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

26th Annual Meeting
Division of Plasma Physics
Boston, Massachusetts
October 29-November 2, 1984

T.L. Rhodes, Roger D. Bengtson, E.J. Powers and Ch.P. Ritz, "Two-Dimensional Structure of the Turbulence in the Edge Plasma of TEXT."

Ch.P. Ritz, Roger D. Bengtson, and E.J. Powers, "Observation of Wave-Wave Interaction in the Edge Plasma of TEXT."

Roger D. Bengtson, Ch.P. Ritz, S.J. Levinson and E.J. Powers, "Turbulent Structure in the Edge Plasma of the TEXT Tokamak."

R.C. Cross, T.P. Kochanski, J.A. Snipes, S.B. Kim and E.J. Powers, "A Typical Magnetic MHD Activity in TEXT."

S.B. Kim, J.A. Snipes, T.P. Kochanski and E.J. Powers, "Soft X-Ray Imaging of Giant Sawteeth and Other Phenomena on TEXT."

Invited Presentation
ONR Contracts Workshop
Naval Research Laboratory
Washington, DC
October 29, 1984

R.M. Walser, "Magnetic Materials Research at The University of Texas."

Seminar
Matsushita Research Institute
Kawasaki, Japan
October 30, 1984

T. Itoh, "Research Operations in the U.S. Universities."

* T. Itoh, "Millimeter Wave Research."

Optical Society of America
San Diego, CA
October 30-November 2, 1984

* Kun-Chi Peng, Ling-An Wu, and H.J. Kimble, "Frequency-Stabilized Nd:YAG Lasers."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Optical Society of America
San Diego, California
October 30-November 2, 1984

* Lung-An Wu and H.J. Kimble, "Role of Phase in Second-Harmonic Generation within an Optical Cavity."

* A.T. Rosenberger, L.A. Orozco and H.J. Kimble, "What is the Best Measure of Cavity Loss in Optical Bistability?"

* L.A. Orozco, A.T. Rosenberger and H.J. Kimble, "Observation of the Single-Mode Instability in Optical Bistability."

* H.J .Kimble and L. Mandel, "Theory of Photoelectric Detection of Polychromatic Light."

Electrochemical Society Symposium
on Compound Semiconductors
New Orleans, LA
October 7-12, 1984

* B.G. Streetman, "Simulation of Concentration-Dependent Diffusion During the Annealing of Ion-Implanted Compound Semiconductors."

Dept. of Aerospace and Ocean Engineering
Virginia Polytechnic Institute
and State University
Blacksburg, Virginia
November 1984

J.L. Speyer, "Optimal Periodic Control."

Colloquium
Laser Science Division
Sandia National Research Labs
November 1, 1984

* John W. Keto, "Dynamics of Two-Photon Excited Xenon Atoms."

Colloquia
Rice University
Houston, Texas
November 6, 1984

M. Fink, "Studies of Metal-Metal By Gas Phase Electron Diffraction."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Colloquia
University of Houston
Houston, Texas
November 7, 1984

M. Fink, "Studies of Metal-Metal by Gas Phase Electron Diffraction."

Washington IEEE MTT-S
Chapter Lecture Series
College Park, MD
November 13, 1984

T. Itoh, "Millimeter Wave Transmission Lines."

EE Seminar
University of Virginia
Charlottesville, VA
November 14, 1984

* T. Itoh, "Millimeter Wave Research at University of Texas."

EE Seminar
University of Texas at Arlington
Arlington, TX
November 15, 1984

* T. Itoh, "Microwave and Millimeter-wave Research at University of Texas at Austin."

Dallas IEEE MTT/AP
Chapter Meeting
Dallas, Texas
November 15, 1984

* T. Itoh, "Microwave Research at The University of Texas."

Dallas IEEE MTT/AP Chapter
Dallas, Texas
November 16, 1984

T. Itoh and T. W. Kennedy, "Problems and Avenues in University-Industry Research Cooperation."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Invited Talk
International Conference on Lasers
San Francisco, California
November 27, 1984

H.J. Kimble, A.T. Rosenberger and L.A. Orozco, "Optical Bistability and Dynamical Instability with Two-Level Atoms."

ARO Workshop on Near Millimeter
Wave Communication Technology
New York Institute of Technology
Glenn Cove, NY
December 5-9, 1984

* T. Itoh, "Millimeter Wave Transmission Lines."

Atomic and Molecular Seminar
Physics Dept.
University of Texas at Austin
Austin, Texas
December 7, 1984

* Jacek Borysow and J.W. Keto, "Raman Induced Kerr Gain Spectroscopy for Argon Dimers."

Semiconductor Research Corporation
Post-Shrink Silicon Device Workshop
Chappel Hill, North Carolina
January 10-11, 1985

* J.L. Erskine, "Experiments, Theory and Predictive Modeling in Relation to 'Post-Shrink Silicon Devices'".

3rd International Modal Analysis Conference
Orlando, Florida
January 29-31, 1985

D.W. Choi, R.O. Stearman and E.J. Powers, "Identification of Aeroelastic Phenomenon Employing Bispectral Analysis Techniques."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Wright Patterson AFB
Wright Patterson AFB, OH
February 1985

*J.L. Speyer, "Fault Tolerant Digital Flight Control Systems."

Advanced Development Group Seminar
McDonnell-Douglas Inc.
St. Louis, MO
February 7, 1985

R.M. Walser, "Thin Film Magnetodielectrics."

Colloquia
Texas A&M University
College Station, Texas
February 12, 1985

M. Fink, "Studies of Metal-Metal by Gas Phase Electron Diffraction."

Aerospace Corporation
Los Angeles, CA
March 1985

*J.L. Speyer, "The Modified Extended Kalman Filter with Applications."

Southwest Conference on Optics
Albuquerque, NM
March 1985

*M.F. Becker, "Surface Potential as a Laser Damage Diagnostic."

Invited Talk
Texas Section of APS Meeting
Rice University
Houston, Texas
March 7, 1985

*H.J. Kimble, "Optical Bistability."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

EE Seminar
Texas A&M University
College Station, TX
March 7, 1985

* T. Itoh, "Microwave and Millimeter Wave Research at The University of Texas."

Texas Section of American Physical Society
Rice University
Houston, Texas
March 8-9, 1985

J. Hartley and M. Fink, "A New Gas phase Raman Spectrometer."

R.J. Mawhorter, J. Hartley and M. Fink, "The Structure of Alkali Chloride Dimer Clusters."

J.D. Coffman and M. Fink, "Shadow Scattering/Does It Exist or Not?"

Hughes Torrance Research Center
Torrance, Ca
March 14, 1985

T. Itoh, "Microstrip Discontinuity Problems."

American Physical Society
Baltimore, MD
March 25-29, 1985

* Ben G. Streetman and C.W. Farley, "Materials Properties of GaAs and Related Compounds."

Workshop on the Estimation and
Control of Stochastic Systems
Dept. of Mathematics
Mexican Polytechnic Institute
Mexico City, Mexico
March 27, 1985

* S.I. Marcus, "Analysis of an Adaptive Estimation Algorithm Arising in the Adaptive Estimation of Markov Chains."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

CONFERENCE PROCEEDINGS

* *A.T. Rosenberger, L.A. Orozco, and H.J. Kimble, "Optical Bistability: Steady State and Transient Behavior," in Fluctuations and Sensitivity in Nonequilibrium Systems, eds. W. Horsthemke and D. Kondepudi, Springer-Verlag, pp. 62-69 (1984).

* *B.G. Streetman and C.W. Farley, "Simulation of Concentration-Dependent Diffusion During Annealing of Ion-Implanted Compound Semiconductors," Journal of Electrochemical Society 131, 468C (1984).

* *S.H. Park and J.K. Aggarwal, "Recursive Synthesis of Linear Time-Variant Digital Filters," Proceedings of the 1984 International Symposium on Circuits and Systems, Montreal, Canada.

M.F. Becker, F.E. Domann, A.F. Stewart and A.H. Guenther, "Charge Emission and Related Precursor Events Associated with Laser Damage," 15th ASTM Laser Damage Symposium, NBS Special Publication, Boulder, CO (1984).

J.L. Erskine, "High Resolution Electron Energy Loss Study of Ordered Structures at Metal Surfaces," 20th Annual Symposium, The New Mexico Chapter of the American Vacuum Society, Albuquerque, NM (April 17-19, 1984).

* *T. Itoh, "Recent Development of Dielectric Waveguide Technology," SPIE Technical Symposium East '84, Arlington, VA, paper no. 477-14, pp. 90-93 (April 29-May 4, 1984).

J.W. Keto, N. Bowering and M.R. Bruce, "Lifetimes and Collisional Deactivation Rates for Xenon $5p^5 6p$", DEAP Meeting of the Am. Phys. Soc. (May 1984).

T. Koh, E.J. Powers, R.W. Miksad and F.J. Fischer, "Applications of Nonlinear Digital Filters to Modeling Low-Frequency, Nonlinear Drift Oscillations of Moored Vessels in Random Seas," Proceedings of the 16th Annual Offshore Technology Conference, Houston, Texas, pp. 309-314 (May 7-9, 1984).

S.B. Kim, T.P. Kochanski, J. Snipes, and E.J. Powers, "Characteristics of Double Sawteeth and Sawtooth-like Oscillations on TEXT," Proceedings of the 1984 IEEE International Conference on Plasma Science, IEEE Catalog No. 84CH1958-8, p. 43, St. Louis, MO, (May 14-16, 1984).

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

S.J. Levinson, E.J. Powers, Ch.P. Ritz and Roger D. Bengtson, "Space-Time Statistics and Particle Transport," Proceedings of the 1984 IEEE International Conference on Plasma Science, IEEE Catalog No. 84CH1958-8, p. 118, St. Louis, MO, (May 14-16, 1984).

Ch. P. Ritz, S.J. Levinson, E.J. Powers, and R.D. Bengtson, "Wave-Wave Coupling and Energy Flow in a Tokamak Edge Plasma," Proceedings of the 1984 IEEE Conference on Plasma Science, Catalog No. 84CH1958-8, p. 118, St. Louis, MO (May 14-16, 1984).

L.Q. Bui, D. Ball and T. Itoh, "Broadband Millimeter-wave E-Plane Bandpass Filters," 1984 IEEE MTT-S International Microwave Symposium Digest, pp. 236-237, San Francisco, CA (May 30-June 1, 1984).

*R. Sorrentino and T. Itoh, "Transverse Resonance Analysis of Finline Discontinuities," 1984 IEEE MTT-S International Microwave Symposium Digest, pp. 414-416, San Francisco, CA (May 30-June 1, 1984).

*Y. Fukuoka and T. Itoh, "Field Analysis of Millimeter-wave GaAs Double-Drift IMPATT Diode in the Travelling-Wave Mode," 1984 IEEE MTT-S International Microwave Symposium Digest, pp. 169-171, San Francisco, CA (May 30-June 1, 1984).

J.L. Erskine, "A Status Report on the Texas/Cornell/Sandia Synchrotron Radiation Beam Line Project," Annual Symposium on Thin Film Processes and Characterization Tools, Dallas, Texas (June 4-5, 1984).

J.L. Erskine, "Adsorbate Structure Determination Using Electron Energy Loss Spectroscopy and a Parameterized Lattice Slab Model", Forty-Fourth Annual Conference on Physical Electronics, Princeton, NJ (June 18-20, 1984).

Y. Fukuoka, Q. Zhang, D. Neikirk and T. Itoh, "Analysis of Multilayer Interconnection Lines for a High Speed Digital Integrated Circuit," International IEEE VLSI Multilevel Interconnection Conference Digest, pp. 246-251, New Orleans, LA (June 21-22, 1984).

*T. Itoh, "CAD-Oriented Field and Network Analysis - Overview," 1984 IEEE AP-S Symposium/National Radio Science Meeting Digest, p. 61, Boston, MA (June 25-28, 1984).

Ch.P. Ritz, S.J. Levinson, E.J. Powers, Roger D. Bengtson and K.W. Gentle, "Turbulence and Energy Cascading in the Edge Plasma of the TEXT Tokamak," Proceedings of the 1984 International Conference on Plasma Physics, vol. I, p. 73, Lausanne, Switzerland (June 27-July 3, 1984).

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

* S.I. Marcus and E.K. Westwood, "On Asymptotic Approximations for Some Nonlinear Filtering Problems," Proc. IFAC Triennial Congress, Vol. VII, pp. 36-41, Budapest, Hungary (July 2-6, 1984).

R.W. Miksad, F.L. Jones and E.J. Powers, "Experiments on Nonlinear Interactions in Wake Transition," Proceedings of the International Union of Theoretical and Applied Mechanics Second Symposium on Laminar-Turbulent Transition, 11 pages, Novosibirsk, U.S.S.R. (July 9-13, 1984).

* T. Itoh, "Survey of New Waveguides," XXIst General Assembly of URSI Digest, p. 294, Florence, Italy (August 28-September 5, 1984).

* T. Itoh, "Fin-Line and E-Plane Structures for Millimeter Wave Circuits," XXIst General Assembly of URSI Digest, p. 434, Florence, Italy (September 5, 1984).

S.W. Yun and T. Itoh, "Nonreciprocal Wave Propagation in a Hollow Image Guide with a Ferrite Layer," 14th European Microwave Conference Proceedings, pp. 341-343, Liege, Belgium (September 10-13, 1984).

Q. Zhang, Y. Fukuoka, T. Itoh and L. Su, "Analysis of a Suspended Patch Antenna Excited by an Electromagnetically Coupled Inverted Microstrip Feed," 14th European Microwave Conference Proceedings, pp. 613-618, Liege, Belgium, (September 10-13, 1984).

D.L. Brower, ..., E.J. Powers, et al., "Tokamaks--Description of Turbulence and the First Test of an Ergodic Magnetic Limiter," Proceedings of the International Atomic Energy Agency Tenth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, London, U.K., (September 12-19, 1984).

* Jae Y. Hong and E.J. Powers, "Simulation Study of Detection of Nonlinear Metallic Targets in Sea Clutter-Type Noise," Proceedings of the 1984 International Symposium on Noise and Clutter Rejection in Radars and Imaging Sensors, Tokyo, Japan (October 22-24, 1984), North-Holland, Amsterdam and New York.

* Y. Fukuoka and T. Itoh, "Travelling-Wave Characteristics of Millimeter-Wave IMPATT Diode, " 9th International Conference on Infrared and Millimeter Waves Digest, p. 528, Takarazuka, Japan (October 22-26 1984).

S.W. Yun and T. Itoh, "Bias Dependence of a Hollow Image Guide Type Isolator," 9th International Conference on Infrared and Millimeter Waves Digest, p. 529, Takarazuka, Japan (October 22-26, 1984).

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

J.L. Erskine, "Inelastic Electron Scattering from Surfaces, Explored Regions and Frontiers", Molecular Dynamics and Surface Chemistry Contractors Conference, p. 45, Albuquerque, New Mexico (October 23-25, 1984).

S. Balakrishnan and J.L. Speyer, "A Coordinate-Transformation Based Filter for Improved Target Tracking," Proceedings of the IEEE Decision and Control Conference (December 1984).

J.L. Speyer and C. Chuang, "Periodic Optimal Hypersonic Scramjet Cruise," Proceedings of the IEEE Decision and Control Conference (December 1984).

R.L. Strong and J.L. Erskine, "Investigation of Underlayer Formation by Oxygen on Al(111) and Ti(001) by High Resolution Electron Energy Loss Spectroscopy and Lattice Dynamical Calculations," 31st National Symposium of the American Vacuum Soc., Reno, Nevada (December 4-7, 1984).

* J.W. Grizzle and S.I. Marcus, "A Jacobi-Liouville Theorem for Hamiltonian Control Systems," Proc. of the 23rd IEEE Conf. on Decision and Control, pp. 1598-1602, Las Vegas, Nevada (December 12-14, 1984).

N. Bowering, T.D. Raymond and J.W. Keto, "Quench Enhancement During Half-Collisions of Laser Excited Xenon Atoms," in Spectral Line Shapes, Vol. 2, Proc. of the 7th Int. Conf., (New York) (1985).

N. Bowering and J.W. Keto, "Selective Quenching During Half-Collisions of Laser Excited Xenon Atoms," in :Proc. of the Int. Conf. on Lasers '84, W.C. Stalley edt., (STS Press) (1985).

B.G. Streetman, "Materials Properties of GaAs and Related Compounds," Bulletin of American Physical Society 30, 450 (1985).

* M.F. Becker, J.A. Kardach, A.F. Stewart and A.H. Guenther, "Surface Potential as a Laser Damage Diagnostic," 16th ASTM Laser Damage Symposium, NBS Special Publication, Boulder, CO (1985).

* M.F. Becker, Y.-K. Jhee and R.M. Walser, "Charge Emission and Accumulation in Multiple-Pulse Damage of Silicon," 16th ASTM Laser Damage Symposium, NBS Special Publication, Boulder, CO (1985).

* M.F. Becker, J.A. Kardach, A.F. Stewart and A.H. Guenther, "Surface Potential as a Laser Damage Diagnostic," Proceedings of the Southwest Conference on Optic, SPIE, Bellingham WA (1985).

PUBLICATIONS, TECHNICAL PRESENTATION, LECTURES AND REPORTS

J.H. Chang, R.O. Stearman, D. Choi and E.J. Powers, "Identification of Aeroelastic Phenomenon Employing Bispectral Analysis Techniques," Proceedings of the 3rd International Modal Analysis Conference, Orlando, Florida, pp. 956-964 (January 28-31, 1985).

M.R. Bruce, N. Bowering, and J.W. Keto, "Collisional Deactivation of Tow-Photon Laser Excited Xenon $5p^5 6p$", Texas Sectional Meeting of the Am. Phys. Soc. (March 1985).

J. Hartley and M. Fink, "A New Gas Phase Raman Spectrometer," Proceedings of the Texas Section of the American Physical Society, Rice University, Houston, Texas, (March 8-9, 1985).

J.D. Coffman and M. Fink, "Shadow Scattering/Does it Exist of Not?", Proceedings of the Texas Section of the American Physical Society, Rice University, Houston, Texas (March 8-9, 1985).

R.J. Mawhorter, J. Hartley and M. Fink, "The Structure of Alkali Chloride Dimer Clusters", Proceedings of the Texas Section of the American Physical Society, Rice University, Houston, Texas (March 8-9, 1985).

I. INFORMATION ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER INFORMATION ELECTRONICS

Research Unit IE84-1 NONLINEAR DETECTION AND ESTIMATION

Principal Investigators: Professor S.I. Marcus (471-3265)
Professor J.L. Speyer (471-4258)

Graduate Students: Jessy Grizzle, Bih-Wan Lin, Taek Song, Evan Westwood and John White

A. OBJECTIVES AND PROGRESS: This research unit is concerned with several aspects of the statistical properties of nonlinear systems. Specifically, the design and analysis of optimal and suboptimal nonlinear estimators, the problem of detecting and identifying failure modes in fault tolerant systems, and the adaptive control and identification of queueing systems have been investigated.

1. Nonlinear Estimation

The nonlinear estimation problem involves the estimation of a signal or state process $x=\{x_t\}$ which cannot be observed directly. Information concerning x is obtained from observations of a related process $z=\{z_t\}$ (the observation process). The objective is the computation, for each t, of least squares estimates of functions of the signal x_t given the observation history $\{z_s, 0 < s < t\}$ -- i.e., the computation of conditional expectations of the form $E[\phi(x_t)\ z_s,\ 0 < s < t]$, or perhaps even the computation of the entire conditional distribution of x_t given the observation history. These state estimates are generated by passing the measurements through a nonlinear system. Optimal state estimators have been derived for very general classes of nonlinear systems, but these are in general infinite dimensional. That is, it is usually not possible to recursively generate the conditional mean of the system state given the past observations. The basic objective here is the design, analysis, and implementation of high-performance optimal and suboptimal estimators which operate recursively in real time.

We have continued our work on a Lie algebraic approach to nonlinear estimation problems. This approach uses the structure of operators occurring in the Zakai equation for the unnormalized conditional density in order to gain an understanding of the structure and difficulty of the estimation problem. In [1], we have written the most comprehensive paper on the subject, stressing the possibilities and limitations of the method. We attempted to combine this approach with asymptotic expansions in order to study estimation in linear systems with infrequently jumping parameters [2]. A typical system of this type is given by

$$dx_t = a(\theta_t)x_t dt + b(\theta_t)dw_t$$

$$dz_t = c(\theta_t)x_t dt + r^{\frac{1}{2}} dv_t$$

where θ is a finite state Markov process taking values in $S=\{1,\ldots,N\}$, and having probability vector $p_t = [p^1, \ldots, p^N]^T$, $p^i = P(x_t=i)$, satisfying

$$p_t = \varepsilon G^T p_t,$$

$\varepsilon>0$. The value of θ_t is called the "regime" at t. We desire to estimate x_t and θ_t given $\{z_s, 0 < s < t\}$. If $\varepsilon = 0$ and the parameter θ is a constant random variable, a finite dimensional filter exists; we are interested in studying the problem for small ε, in which case the parameters are "jumping infrequently". It can be shown that a true asymptotic expansion exists; however, for all but the first term, it cannot be shown that the individual terms in the expansion can be computed with finite dimensional filters, since infinite dimensional Lie algebras arise. Therefore, in [2] the zero-th order filter is compared via simulation to other filters, many of which perform better. *It is concluded that the applicability and utility of these methods is highly problem-dependent.*

A new globally convergent nonlinear observer, called the modified gain extended Kalman observer (MGEKO), has been developed for a special class of systems [3,4]. This special class of systems is characterized by special nonlinearities in either the dynamics or measurements, called modifiable nonlinearities. A vector function $a(x)\varepsilon\, \mathbb{R}^q$ is a modifiable nonlinearity if there exists a qxn matrix $g(z^*,\bar{x})$ so that for $x,\bar{x}\varepsilon\, \mathbb{R}^n$

$$a(x)-a(\bar{x}) = g(z^*,\bar{x})(x-\bar{x})$$

where $z^*=h(x)$ is the measurement function. If a system is composed of only this class of nonlinear functions, then the error in the estimate is propagated by a linear equation whose coefficients are functions of z^* and x. The globally convergent property of the associated nonlinear observer is found by using a quadratic Lyapunov function of the estimation errors.

If this observer is used in a noisy environment, then biased estimates result. This is because both the residual and the gain are functions of the present measurement and, therefore, are correlated. To avoid this effect, the algorithm is modified so that the gain is not a function of the present measurement. Although some reasonable but uncheckable assumptions are required, the filter, called the modified gain extended Kalman filter (MGEKF), is shown under certain side conditions to be exponentially bounded in mean square. This

result is obtained by first constructing an unrealizable but exponentially bounded filter used as the nominal from which the sufficiency condition for exponential boundedness of the MGEKF is obtained.

Although the class of modifiable functions is quite small, it does include some important engineering estimation problems. In [3] the bearings-only measurement problem is described; in this problem, the angle measurements are linear in a spherical coordinate frame and the dynamics are linear in a rectangular coordinate frame. Although the bearings-only measurement in two dimensions is modifiable in a rectangular coordinate frame, the vector bearings-only measurement is approximately modifiable in three dimensions. Nevertheless, simulations revealed stable and unbiased behavior in the noisy measurement case, thus showing superior performance with respect to existing filter mechanizations. In [4] the problem of state and parameter identification is shown to fit into the class of modifiable functions. Choice of the coordinate frame is shown to be crucial. The results show dramatic improvement over previously published results for the extended Kalman filter.

The research in this area is continuing and has been complemented by Grants AFOSR-79-0025 and AFOSR-84-0371 from the Air Force Office of Scientific Research, and Grant ECS-8412100 from the National Science Foundation.

2. Fault Detection and Identification

An essential aspect in the design of fault tolerant digital flight control systems is the design of failure detection and redundancy management systems. In analytic redundancy, dissimilar instruments are combined through analytic relations to achieve redundancy. The processing of the outputs of these relations to produce adequate fault detection and isolation performances may require complex decision and estimation software. Detection filter theory constitutes a technique for generating closed-loop residuals which have directional characteristics that are useful for fault detection and identification (FDI). The essential idea of this theory is that of choosing the gains of a linear filter (or observer) from a deterministic analysis in such a way that the closed-loop system output error has directional properties which can be directly associated with a particular failure mode when a failure has occurred. A detection filter acts in a closed-loop fashion to fix the output error direction associated with a set of plant and/or actuator failures, while restricting the output error direction of sensor failures in the set to lie in a plane. The output error direction(s) can then be employed to detect and identify the failure source by association with the design failure direction set. If two or more failure modes have identical output error directions, then the identification process becomes more involved, since failure magnitude information must then be used to differentiate

between potential failure sources. An interesting and potentially useful characteristic of this closed-loop technique, as opposed to the open-loop parity error method [5], is that the output error magnitude never completely disappears. If some failure occurs whose direction has not been designed into the detection filter, then the output error direction will not generally be useful for FDI. As with all FDI systems, the proper determination of the failure modes for which the system will test is imperative. If more design failure directions exist than can be designed into a single detection filter, then multiple detection filters will be required.

The concept of the detection filter was introduced by Beard [6] and further examined by Jones [7]. The approach taken by Beard essentially revolves around the determination of a cyclic basis representation [8] for the closed-loop system; this representation satisfies certain constraints that are imposed to force the unidirectionality of the output error in response to a design failure direction. The basic approach in this work was apparently motivated by the control decoupling problem, which is the dual of the detection filter problem. Unfortunately, the approach suffers from the fact that it produces an analysis which is rather indirect and overly complicated. Furthermore, some of the concepts which are essential to the developments of [6,7] are generally unfamiliar to most engineers. These facts have apparently hampered the implementation of the detection filter theory, since neither of these dissertations has generated a paper in the open literature.

A new derivation for the determination of detection filters has been developed by using an eigensystem assignment approach [9]. This approach is not only conceptually simpler, but by building on the filter closed-loop eigenvalues and eigenvectors explicitly, the physical interpretation of the performance of the detection filter is much more transparent. Two constraints are imposed on the detection filter design. First, given a failure direction in the dynamic system, the measurement residual must maintain a fixed direction. Secondly, the closed-loop eigenvalues can be specified arbitrarily. The design procedure is that of determining the closed-loop eigenvectors and filter gains, given a set of failure directions and all the closed-loop eigenvalues. Under certain assumptions, it is shown that a set of eigenvectors is associated with each fault direction. Since the number of fault directions is usually less than the number of state variables, it is not known how many eigenvectors are assigned to each fault direction. To determine this number, called the dimension of the detection space, detailed information concerning the structure of the error state space (where the error is defined as the difference between the state variable and the state estimate from the detection filter) with respect to each fault direction is required. It is shown that the error state space is decomposed into overlapping spaces (called detection spaces) with respect to each fault direction. This

decomposition is obtained by a simple projection technique in which a new state space is constructed for which a particular fault direction is not observable. The null space of the observability matrix is the detection space with respect to the particular fault, and the dimension of the detection space is easily determined. If the sum of the dimensions of the detection spaces (the number of measurements is assumed in this presentation to be equal to the number of fault directions) is equal to the state dimension, then all requirements are met to determine the eigenvectors and the detection filter gains.

If the sum of the dimensions of the detection spaces for each fault direction do not add up to the state dimension, then there are unassignable closed-loop eigenvalues which are associated with an excess space. This violates one of the constraints on detection filter design. One method for circumventing this difficulty is to enlarge the state space with additional observable but uncontrollable dynamics to form an input-output equivalent realization. Another area of interest is called output stationarity. If the freedom to arbitrarily choose the closed-loop eigenvalues is somewhat restricted, it is shown that more failure directions than the number of measurements can be accommodated by one detection filter. Although unassignable eigenvalues can occur, by enlarging the state space this difficulty can again be circumvented.

Future research is concerned with ensuring that the fixed output residual directions due to a prescribed failure direction be robust in the presence of parameter variations, unmodeled dynamics, and additive sensor and process noise.

This research is continuing and is complemented by a grant from General Dynamics Corporation.

3. Identification and Adaptive Control of Queues

Closely related to the parameter identification and fault identification problems discussed above are estimation and control problems involving unknown parameters. In such problems, parameter identification algorithms are of interest; even more important is the on-line use of these algorithms in adaptive estimation and control algorithms.

In [10], we consider the priority assignment (or dynamic scheduling) problem in a queueing system with unknown arrival and service rates, and average cost criterion with linear cost rates. An optimal adaptive policy is determined via the direct, elementary approach of a naive feedback controller. We have considered in [11] discounted-reward finite state Markov decision processes which depend on unknown parameters. An adaptive policy inspired by the nonstationary value-iteration scheme of Federgruen and Schweitzer [12] is proposed. This policy is briefly compared with the "principle of estimation and control" recently obtained by Schal [13].

In related work, we have in [14] presented a distance-measures approach to the problems of identification and approximation of queueing systems. This approach combines ideas from statistical robustness, information-type measures and parameter-continuity of stochastic processes.

The research in this area is continuing and is complemented by Grant AFOSR-84-0089 from the Air Force Office of Scientific Research.

C. REFERENCES

1. S.I. Marcus, "Algebraic and Geometric Methods in Nonlinear Filtering," Siam J. Control and Optimization, Vol. 22, pp. 817-844 (November 1984).

2. S.I. Marcus and E.K. Westwood, "On Asymptotic Approximations for Some Nonlinear Filtering Problems," Proc. IFAC Triennial Congress, Vol. VII, pp. 36-41, Budapest, Hungary (July 2-6, 1984).

3. T.L. Song and J.L. Speyer, "A Stochastic Analysis of a Modified Gain Extended Kalman Filter with Applications to Estimation with Bearings-Only Measurements," to appear in the IEEE Trans. Automatic Control (Oct. 1985).

4. T.L. Song and J.L. Speyer, "The Modified Gain Extended Kalman Filter and Parameter Identification in Linear Systems", to be published in Automatica.

5. E.Y. Chow and A.S. Willsky, "Analytic Redundancy and the Design of Robust Failure Detection Systems," IEEE Trans. Automatic Control, Vol. AC-29, No. 7 (July 1984).

6. R.V. Beard, "Failure Accommodation in Linear Systems Through Self-Reorganization," Report No. MUT-71-1, Man-Vehicle Laboratory, M.I.T., Cambridge, MA. (February 1971).

7. H.L. Jones, "Failure Detection in Linear Systems," Report No. T-608, The Charles Stark Draper Laboratory, Cambridge, MA. (August 1973).

8. T. Kailath, Linear Systems, Englewood Cliffs: Prentice-Hall (1980).

9. J.E. White and J.L. Speyer, "Detection Filter Design by Eigensystem Assignment," Proc. 1985 American Control Conference (June 1985).

10. O. Hernandez-Lerma and S.I. Marcus, "Optimal Adaptive Control of Priority Assignment in Queueing Systems," Systems and Control Letters, Vol. 4, pp. 65-72 (April 1984).

11. O. Hernandez-Lerma and S.I. Marcus, "Adaptive Control of Discounted Markov Decision Chains," to appear in J. Optimization Theory and Applications (June 1985).

12. A. Federgruen and P.J. Schweitzer, "Nonstationary Markov Decision Problems with Converging Parameters," J. Optimization Theory and Applications, Vol. 34, pp. 207-241 (1981).

13. M. Schal, "Estimation and Control in Discounted Stochastic Dynamic Programming," University of Bonn, Institute of Applied Mathematics, Preprint No. 428 (1981).

14. O. Hernandez-Lerma and S.I. Marcus, "Identification and Approximation of Queueing Systems," IEEE Trans. Automatic Control, Vol. AC-29, pp. 472-474 (May 1984).

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE84-2 ELECTRONIC TIME-VARIANT SIGNAL PROCESSING

Principal Investigator: Professor J.K. Aggarwal (471-1369)

Graduate Students: T. Leou, N. Nandhakumar and S. Park

A. OBJECTIVES AND PROGRESS: The main objectives of this research unit are to explore the basic properties of linear time-variant (LTV) systems and to develop efficient techniques for processing time-variant signals. Our recent research focuses on the analysis, synthesis and implementation of recursive LTV filters in both time and frequency domains. In particular, we are interested in exploring new filter structures for realizing recursive LTV filters and in reducing the complexity of the synthesis algorithms involved. The progress of this research unit is summarized in the following.

We have established the framework for the analysis and synthesis of LTV digital filters by investigating the interrelationships among the three common characterizations of LTV filters; the time-variant impulse response, the generalized transfer function and the time-variant difference equation [1]. We have shown that a causal impulse response is realizable as a time-variant difference equation if and only if it is expressed as a separable causal sequence. As documented in [2], we have proposed an efficient technique to determine the frequency characteristics of LTV filters from the short-time Fourier transform properties. We have shown that the use of an LTV filter in processing time-variant signals may significantly reduce the required bandwidth of the filter. Further, we have developed two synthesis techniques for recursive LTV filters based on the minimization of the squared difference between the desired and the synthesized impulse responses [3]. The first technique is formulated as a spectral decomposition of the desired impulse response and the second technique is based upon a nonlinear minimization algorithm. As reported in [4], we have developed a technique to implement a one-dimensional (1-D) LTV filter with a two-dimensional (2-D) LTI filter by appropriately mapping 1-D input/output sequences into 2-D sequences. Therefore, a 1-D LTV filter synthesis problem can be solved by the synthesis techniques developed for 2-D LTI filters.

Continuing our research on the synthesis of an LTV filter as an LTV difference equation, we have studied the relationship between a rational generalized transfer function (GTF) and the corresponding difference equation based upon a difference equation representation of the GTF [5],[6]. The synthesis of a rational generalized transfer function as a time-variant difference equation has been formulated by minimizing a Chebyshev norm of a residual vector which represents a distance measure between the desired GTF and the GTF realizable as an LTV difference equation. The realizability of a GTF as a time-variant difference equation can be determined by examining whether there

exists a time-variant difference equation making the residual vector vanish. We have shown that there always exists an exact realization of a GTF having constant denominator coefficients. The coefficients of the corresponding time-variant difference equation at each sampling instant can be determined by solving two linear equations. A simple two-stage structure to implement a rational GTF having constant denominator coefficients is proposed, where the coefficients of the recursive structure are in one-to-one correspondence with those of the GTF.

As reported in [7], we have proposed to implement an LTV filter as a parallel connection of linear time-invariant (LTI) digital filters followed by time-variant multipliers. The desired impulse response is decomposed into a sum of products of two orthogonal sequences via the use of spectral decomposition. Then we choose a small number of dominant terms in the sum of products as an approximation of the desired impulse response. A simple filter structure is obtained by properly modifying the sequences to realize the parallel structure as a cascade sections of first- and second-order recursive LTI filters. The LTV filters synthesized with the cascade structure require less computation and storage space.

In [8], we have highlighted the misconception of synthesizing a recursive LTV filter based on the idea of frozen-time transfer function. We identify the special cases where the frozen-time synthesis technique produces satisfactory results. A typical synthesis problem has been selected as the illustration of the difference between the desired transfer function and the transfer functions synthesized via the frozen-time technique.

The research work on time-variant signal processing is continued. In particular, we are investigating the basic properties of recursive LTV filters represented in the state variable form. A time-dependent state transformation can define an equivalent filter having diagonal state-feedback matrices. An efficient solution to the structure-independent synthesis of recursive LTV filters is also under study. In addition, we are investigating the relationship between a continuous-time system and its discrete-time counterpart.

B. REFERENCES

1. N.C. Huang and J.K. Aggarwal, "On Linear Shift-Variant Digital Filters," IEEE Transactions on Circuits and Systems, Vol. CAS-27, No. 8, pp. 672-679 (August 1980).

2. N.C. Huang and J.K. Aggarwal, "Frequency Domain Consideration of LTV Digital Filters," IEEE Transactions on Circuits and Systems, Vol. CAS-28, No. 4, pp. 279-287 (April 1981).

3. N.C. Huang and J.K. Aggarwal, "Synthesis and Implementation of Recursive Linear Shift-Variant Digital Filters," IEEE Transactions on Circuits and Systems, Vol. CAS-30, No. 1, pp. 29-36 (January 1983).

4. S.H. Park, N.C. Huang and J.K. Aggarwal, "One-Dimensional Linear Shift-Variant Digital Filtering Using Two-Dimensional Techniques," IEEE Transactions on Circuits and Systems, Vol. CAS-30, pp. 172-176 (March 1983).

5. S.H. Park and J.K. Aggarwal, "Recursive Synthesis of Linear Time-Variant Digital Filters," 1984 International Symposium on Circuits and Systems, Montreal, Canada (May 7-10, 1984).

6. S.H. Park and J.K. Aggarwal, "Recursive Synthesis of Linear Time-Variant Digital Filters via Chebyshev Approximation," IEEE Transactions on Circuits and Systems, Vol. CAS-32, No. 3, pp. 245-251 (March 1985).

7. S.H. Park and J.K. Aggarwal, "A Simple Form Realization of Linear Time-Variant Digital Filter via Spectral Decomposition of Its Impulse Response," Journal of the Franklin Institute, Vol. 318, No. 3, pp. 151-164 (September 1984).

8. T.Y. Leou and J.K. Aggarwal, "Recursive Implementation of LTV Filters---Frozen-Time Transfer Function Versus Generalized Trarsfer Function," Proceedings of the IEEE, Vol. 72, No. 7, pp. 980-981 (July 1984).

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE84-3 DIGITAL TIME SERIES ANALYSIS WITH APPLICATIONS TO NONLINEAR WAVE PHENOMENA

Principal Investigator: Professor E.J. Powers (471-3954)

Research Associate: Dr. Christoph Ritz

Graduate Student: Taiho Koh

A. OBJECTIVE: The overall scientific objective of this research unit is to conceive and implement unique digital time series analysis techniques that may be used to analyze and interpret nonlinear wave fluctuation data in such a way as to provide new experimental and physical insight into a variety of important nonlinear wave phenomena. Our approach is multidisciplinary and rests upon synthesizing appropriate knowledge from the fields of nonlinear waves, nonlinear systems, and digital signal processing. Particular emphasis is placed upon modelling the linear and nonlinear relationships between two (or more) time series in the frequency domain via a hierarchy of linear and nonlinear transfer functions. Such transfer functions are closely related to the relevant physics in that the transfer functions are a measure of the "efficiency" with which various spectral components in the input mix to transfer energy to new spectral components in the output. Although the primary focus of this research unit has been on frequency domain modelling of nonlinear systems, time-domain models based on second-order Volterra filters are also being investigated. We anticipate that the results of this research will continue to impact on many important scientific and technological problems, some of which are discussed in the next section.

B. PROGRESS: The majority of our earlier work was concerned with the analysis of single time series of fluctuation data associated with various nonlinear wave phenomena. The thrust of our current research is concerned with considering two (or more) channels of fluctuation data and developing digital time series analysis techniques that will enable one to identify and model the linear/nonlinear relationships (if any) between the two time series. The primary emphasis in the past has been on frequency domain modelling, however, we have made progress in time-domain modelling with the aid of second-order Volterra filters. Our progress, which is summarized in the following paragraphs, may be subdivided into the following areas: (1) nonlinear systems modelling in the frequency domain with applications, (2) nonlinear systems modelling in the time domain with applications, and (3) efficient correlation function estimator of Gaussian processes. The latter topic is not directly related to nonlinear systems modelling, but is more in the nature of a spin-off of our current work.

Nonlinear Frequency-Domain Models: We have developed a conceptual nonliner systems model in the frequency domain that corresponds to the Fourier transform of an orthogonalized Volterra functional series model in the time domain [1]. This model is valid for zero-mean Gaussian inputs with arbitrary spectral density. The model consists of a parallel combination of linear, quadratic, cubic, etc., transfer functions such that when the actual input is applied to the model, the model output approximates the output of the actual physical very well. In particular the concept of coherency has been extended to quantify the goodness of the model.

Of particular importance is the fact that the model indicates how the linear, quadratic, and cubic transfer functions may be estimated by computing the cross-power, cross-bispectrum, and cross-trispectrum, respectively, given the actual input and output time series data. Computer programs have been written to estimate such transfer functions. The validity of the model and the computer software have been validated by applying them to a variety of scientific and technological problems, some of which are described in the following paragraphs.

The first application involves electromagnetic scattering from nonlinear objects such as man-made metallic objects. It is well known that the I-V characteristics of the junctions associated with metallic joints often are nonlinear and are predominately cubic. In the past [2] we proposed a conceptual model which enables one to systematically characterize a nonlinear target in terms of a hierarchy of linear, quadratic, and cubic cross-sections. Such cross-sections are similar to the linear and nonlinear transfer functions used to model nonlinear systems and can be computed, using higher order spectral analysis techniques, from knowledge of the incident and scattered signals. In a recent conference paper [3], we demonstrated that digital cross-trispectral techniques may be utilized to detect (cubically) nonlinear metallic targets under severely interfering sea clutter-type noise.

Another important application area involves the use of auto- and cross-bispectral analysis techniques in identifying various aeroelastic phenomena. In ref. [4] these bispectral analysis techniques are used to experimentally identify different classes of auto-parametric responses and finally the onset of flutter-type instabilities. In particular, a new subcritical flutter testing technique, based on bispectral analysis, was proposed and tested.

Nonlinear Time-Domain Models: The representation of nonlinear system models in terms of Volterra functional series is well known [5]. While most of the current signal processing techniques are based on linear system models, there has been a growing interest in utilizing Volterra series in digital filtering and estimation of stationary time series. A major problem in the use of Volterra-type nonlinear digital filters is the computational complexity associated with the design and implementation of such filters. The complexity is rather formidable

due to their multi-dimensional convolutional structure and higher-order statistical characteristics. We have investigated the problem of second-order Volterra filtering with the emphasis on reducing the computational complexity where possible. A simple minimum mean square error solution for the Volterra filter has been obtained based on the assumption that the filter input is Gaussian, and an adaptive filtering algorithm for the filter has been developed [6]. The performance of the adaptive algorithm has been studied with a detailed analyses of its mean convergence and asymptotic excess mean square error [7]. We also developed an iterative factorization technique for the second-order Volterra filter [7], which drastically reduces the complexity of the filter implementation by employing a special filter structure. Furthermore, the practical usefulness of these techniques have been demonstrated in terms of an offshore engineering problem [8,9] involving modeling and predicting the nonlinear low-frequency large-amplitude oscillations of moored vessels subject to random sea waves.

Efficient Correlation Function Estimator of Gaussian Processes: The computation of correlation function estimates is an important task in time series modeling since they provide crucial statistical information which is required in many time series modeling techniques. While conventional approaches require a large number of multiplications in estimating the correlation functions, several researchers proposed new methods in which the correlation function estimates are computed with additions only [10,11]. These methods employ a nonlinear distortion to exploit the prior knowledge of Gaussian statistics and are very suitable for digital implementation due to the non-multiplicative property. However, while the computational merit of these methods seems quite encouraging, their detailed performance has not been fully understood until recently. So, our primary concern in this study was aimed at a comparative performance evaluation between the new and conventional methods by investigating their first and second order statistics. Exact expressions for the means and variances of these estimators were formulated and utilized. As a result, it was pointed out that, in addition to their computational merit, the performance of these new methods compares favorably to the conventional approaches. In addition, we developed a non-multiplication method for the maximum entropy spectral estimation, which is an extension of the previous non-multiplication correlation function estimators, and showed that this method is useful in fast computation of maximum entropy spectra [12].

C. References

1. J.Y. Hong and E.J. Powers, "On Modelling Nonlinear Systems in the Frequency Domain", to be submitted for publication.

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2. E.J. Powers, J.Y. Hong and Y.C Kim, "Cross Sections and Radar Equation for Nonlinear Scatterers", IEEE Transactions on Aerospace and Electronic Systems, AES-17, 602-605 (July 1981).

3. J.Y. Hong and E.J. Powers, "Simulation Study of Detection of Nonlinear Metallic Targets in Sea Clutter-Type Noise," Proceedings of the 1984 International Symposium on Noise and Clutter Rejection in Radars and Imaging Sensors, edited by T. Musha, T. Suzuki, and H. Ogura, Tokyo, Japan (October 22-24, 1984).

4. J.H. Chang, R.O. Stearman, D.W. Choi and E.J. Powers, "Identification of Aeroelastic Phenomenon Employing Bispectral Analysis Techniques," Proceedings of the 3rd International Modal Analysis Conference, Orlando, Florida, pp. 956-964 (January 28-31, 1985).

5. M. Schetzen, "Nonlinear System Modeling Based on the Wiener Theory," Proc. IEEE, Vol. 69, No. 12, pp. 1557-1573 (Dec. 1981).

6. T. Koh and E.J. Powers, "An Adaptive Nonlinear Digital Filter with Lattice Orthogonalization," Proc. 1983 IEEE Int. Conf. on Acoust., Speech, and Signal Processing, pp. 37-40 (April 1983).

7. T. Koh and E.J. Powers, "Second-Order Volterra Filtering and Its Application to Nonlinear System Identification," accepted for publication in IEEE Trans. on Acoust., Speech, and Signal Processing.

8. T. Koh, E.J. Powers, R.W. Miksad and F.J. Fischer, "An Approach to Time Domain Modeling of Nonlinear Drift Oscillations in Random Seas," Offshore Engineering, Vol. 4, F.L.L.B. Carneiro, A.J. Ferrante, and R.C. Batista, Editors, Pentech Press, London, pp. 137-153 (1984).

9. T. Koh, E.J. Powers, R.W. Miksad and F.J. Fischer, "Application of Nonlinear Digital Filters to Modeling Low-Frequency Drift Oscillations of Moored Vessels in Random Seas," Proc. 1984 Offshore Tech. Conf., pp. 309-314 (1984).

10. D. Hertz, "A Fast Digital Method of Estimating the Autocorrelation of a Gaussian Stationary Process," IEEE Trans. on Acoust., Speech, and Signal Processing, Vol. ASSP-31, pp. 1023-1025 (April 1982).

11. T. Koh and E.J. Powers, "Efficient Methods to Estimate Correlation Functions of Gaussian Processes and Their Performance Analysis," to appear in IEEE Trans. on Acoust., Speech and Signal Processing.

12. T. Koh and E.J. Powers, "Efficient Maximum Entropy Spectral Estimation Using Non-Multiplication Methods," Proc. 1984 IEEE Int. Conf. on Acoust., Speech and Signal Processing, pp. 13.2.1-13.2.3 (March 1984).

II. SOLID STATE ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE84-1 SOLID STATE INTERFACE REACTIONS AND INSTABILITIES

Principal Investigators: Professor R.W. Bene' (471-1225)
Professor R.M. Walser (471-5733)

Graduate Students: H. Ehsani, Segeun Park and Won Woo Park

A. RESEARCH OBJECTIVES: The overall objectives of this unit are to increase our understanding of the instabilities which lead to the interface structures (such as compounds) which occur under a variety of initial conditions and growth environments. Another objective is to understand the electrical, magnetic and physical properties of these interface structures. The ultimate goal of these objectives is to attain the status of being able to predict interface structures and their properties for the synthesis of new materials and devices.

A specific objective of this work is to arrive at a phenomenological prediction of first phase formation of ternary (or higher) systems as we have for the binary systems (metal-Si, metal-Ge, metal-metal). In particular, we would like to be able to predict first phase nucleation in metal-(compound semiconductor) and (metal alloy)-Si systems.

The second specific objective is to understand these solid state reactions in terms of the thermodynamic paths leading to the instabilities. In particular, how does a system select its operating point from the whole possible range of possible operating points along the path of instabilities.

Our work on the first specific objective consists of two parts. First a review of the literature of metal in contact with compound semiconductor has turned up a problem which is much more prevalent than in metal - Si systems. This problem is the disagreement between even first rate research groups of first compound nucleation. For example, five recent studies of Pd on GaAs produced five different results. Assuming the work was of good quality, there are several possible reasons for this which come to mind: (1) results are critically dependent on preparation; (2) results are dependent on really significant difference - i.e., sputtering vs. evaporation; and (3) it is hard to separate first phase nucleation from that of the second or third phases because of the increased number of states among three or more elements. The first reasons two lead to real changes in first phase nucleation while the third does not. We have undertaken work on some systems in an attempt to help up "read" the results of other experiments in order that we may establish the probability that the stated first phase really was the first phase.

The other part of our work directed toward satisfying the phenomenological prediction of phase formation, is to extend the data base on other systems ourselves. To this end we are in the process of TEM/TED

studies of the following systems:

metals on $Hg_{1-x}Cd_xTe[MCT(x)]$
Cu on MCT (x=.2, 1)
Co on MCT (x=.2, ?)
Ni on MCT (x=.2, .3, 1)

ultra thin sequenced layer and co-deposited alloys on silicon

- Ti and Co on Si
- Ti and Ni on Si
- Ti and Al on Si
- Co and Al on Si

Our work on the second specific objective (a thermodynamic understanding of the reaction path) is being pursued both experimentally and theoretically. Since first phase nucleation seems to be a kinetically selective process, we have been looking at the macroscopic properties of the interface which would be important in a thermodynamic description of the kinetics - such as freedom of atomic movement and fluctuations. Specifically, in metal-silicon systems in the prenucleation regime, we have been measuring metallicity and stress development as the metal thickness and temperature is increased up to, and past, first compound (and sometimes second and third) nucleation. Fluctuations are being studied by "1/f" noise studies and low frequency dielectric response.

Another objective of this research is to investigate the effect of impurities on interface reactions. A problem of great interest in this respect is to understand the profound effect that small impurity concentrations (typically $10^{20} cm^{-3}$) have on the kinetics of solid phase reactions. In our research we are concentrating on systematically understanding the effect that hydrogenic dopants have on the kinetics on the solid phase epitaxial regrowth (SPEG) of self-ion amorphised silicon.

The specific objective of this work in the past year has been to measure the concentration dependence of the silicon SPEG kinetics with sufficient precision to determine whether this effect for a specific impurity is enthalpic or entropic. Previous experiments utilizing

Rutherford backscattering spectrometry (RBS) of isochronally annealed samples lack the necessary experimental precision required for the modelling which can only be achieved by using some type of in-situ, continuous monitor of the regrowth kinetics of comparable resolution to RBS. In principle, an in-situ laser interferometric measurement of the motion of the epitaxial interface can satisfy these requirements and several SPEG regrowth measurements using this technique have been reported. To date, however, all of these measurements have been made during short pulse laser annealing in which there is a large temperature transient the calculation of which is highly model dependent.

To eliminate these difficulties our approach has been to conduct in-situ laser interferometric measurements of SPEG with a temperature controlled vacuum furnace. This system was built earlier and described in previous reports of this work and a schematic is shown in Figure 1.

Previous work on the effect of impurities on SPEG have implicitly assumed that the effect of the impurities on altering the regrowth rate is to modify an enthalpic barrier; e.g., a diffusion barrier, interface bond formation, etc. There is the possibility, of course, that the effect it entropic and, if true, it would have great impact on the modelling of such processes. To distinguish between these effects we have used the system in Figure 1 to measure the impurity concentration dependence of silicon (100) SPEG as described in the next section.

B.. PROGRESS: During the past year we have made significant progress toward our stated objectives. We have finished the TEM/TED of Pd:GaAs samples prepared by sputtering at room temperature. Our results are in agreement with recent results of an IBM (1) group which were done for much thicker films at much higher temperatures (reaction temperature was ≅ 250^{0}C for that study). The first phase observed in our study at room temperature was that of a structure consistent with Pd_2GaAs. However, these results seem to be in disagreement with those from a group at Stanford (2) where an arsenide reaction plus free gallium was observed at room temperature (no structural data). These data would be reconciled if there is a difference in compound nucleation if the film is sputtered vs. evaporated, so we plan to also perform our ultra thin film structure studies using e-beam evaporation.

We have essentially finished studies of Cu and Co on MCT (.2, 1) for samples prepared by metal sputtering. These results are being prepared for publication (student is H. Ehsani) and a summary of the results follows.

(A) The Cu-CdTe and MCT(.2) System

It was found that Cu reacted with both systems at room

temperature. The Cu initially formed Cu_2Te, but over a period of hours, the sample was oxidized to $CdTeO_3$ with no hint of the location or state of the Cu. (This is consistent with the Cu_2Te being unstable with respect to oxidation). Since Cu is known to be a fast diffuser in these systems it is assumed that the Cu had diffused into the substrate. At first it was surprising that any Cu compound was formed in a thick enough layer to be seen by TED at all, since all of the possible reactions of Cu with CdTe or MCT(.2) are energetically unfavorable. It should be noted that these systems do satisfy the $\Delta H_R < + .5$eV/atom given by Brillson [3] for the presence of a surface reaction - but it is still surprising that it would form a compound. A little Te and/or TeO_2 was sometimes seen after substrate preparation and before sputtering of the metal. However, the amount and surface coverage of the Te was small and was not visible at all (by TED) for most of the samples.

(B) The Co-CdTe and MCT(.2) Systems

We looked at these systems next because (i) compound formation is energetically favorable for MCT(.2), and (ii) it is not for CdTe.

The results were different for MCT(.2) and CdTe. Basically in the Co-MCT(.2) system a Co_3T_4 (γ phase) compound was nucleated in the interface region at room temperature. The crystals then grew considerably for low temperature anneals. However, in the Co-CdTe system we observed Te at room temperature after deposition, but the γ phase did nucleate and grow until we annealed at temperature greater than 300^{0}C.

Since the growth of crystals did occur with annealing time, again the reaction would <u>seem</u> to be going uphill in energy. This is highly unlikely, and a more probable explanation is that the metals are not reacting with CdTe but with Te. Additionally, the phases found for both the Cu and Co systems satisfies the first nucleation rule within the Cu-Te and Co-Te binary phases for MC systems (metal-covalent bonding) (4).

After substrate preparation (before film deposition) generally Te was not observed by TEM. When we heated the substrates to test for thermal generation of Te under metal deposition, Te did appear, but the temperatures required were well outside the possible thermal generation range of the thin film deposition process, <u>and</u> the Te was not observed over the entire surface.

Thus, these results raise several questions of importance concerning the interface phase formation and its stability for metal/-MCT(x) contacts.

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(1) What determines the availability of Te for compound nucleation with the contacts? How much is a thermal effect? How much is a chemical effect? How much is due to the disorder inevitably produced at the surface by the sputtering process?

(2) Is compound formation with metals always determined by the production of free Te by one of the above processes, so that compound formation is predictable from the metal-Te phase diagrams from the MC rule?

(3) What are the roles of the energetics of the substrate MCT(x), and ΔH_f for each metal in both of the above? How does the Brillson criteria for surface reactions come into play when the energetics are unfavorable for metal - MCT(x) compound formation?

Besides being of technological importance, the metal-MCT(x) systems are scientifically very versatile. Not only can we change the energetics of the reaction by using different metals, but also within a single metal - MCT(x) system, we can vary the energetics over a large range by varying x (i.g. favorable for reaction, to unfavorable for reaction). The combination allows for the chance of separating the effect of overall reaction energetics from the ease of producing surface Te (which we may expect to be a function of the substrate heat of formation or perhaps Hg content).

Work on the Ti-Co system on Si substrates is essentially complete for both sputtering and high vacuum e-beam evaporation. The thin films we sequentially deposited for various thicknesses, and also co-evaporated using two sources. It was found that the lowest eutectic between the two binary systems (i.e., lowest of T_E's among the binary phase diagrams) involved, determine compound nucleation even for T_E's only 50^0C apart. $CoTi_2$ was the first phase formed, not Co_2Si for the combination Ti-Co-Si, where depositions were done by evaporation. Under deposition by sputtering the above sequence always resulted in Co_2Si formation. When the sequence was reversed Co-Ti-Si, $CoTi_2$ always formed first, followed by TiSi epitaxial, no equilibrium phase) and $CoSi_2$ (epitaxial) + TiSi (non equilibrium-epitaxial) following in rapid sequence at 500^0C. The epitaxial $CoSi_2$ was found to be under the TiSi (non equilibrium) by Auger Spectroscopy. This work will soon lead to a Ph.D. degree (H.Y. Yang) and probably two publications.

Another system with a significant amount of work in the past year has been the Ti-Al-Si system (sequential thin film) prepared by sputtering. The first phase in this system is a nonequilibrium phase and appears related to the $TiAl_3$ and previously observed "Ti_8Al_{24}" phases. This work will be published shortly and will result in a

masters degree for the student involved (C.C. Han).

Finally, we are making progress on in-situ stress studies of Co on Si systems and a thermodynamic stability analysis of all of these systems. However, it is premature to give results at this time.

During the past year we have been studying the effect of ion implanted boron and phosphorus on silicon SPEG. The results for phosphorus are now largely complete. A profile of the P distribution implanted in (100) silicon is shown in Figure 2. A typical laser interferometry transient of the SPEG of this sample at 475^{0}C is shown in Figure 3. This date can be to determine the time-dependent position of the interface as shown in Figure 4. By comparing the data of Figures 2 and 4, the variation of the SPEG velocity with impurity concentration can be determined and, if this data is determined at a number of temperatures, the enthalpic (exponential) and entropic (pre-exponential) factors can be obtained. The small change of these quantities with concentration; the enthalpy change produced by 0.1%P, for example, was typically <50 meV; make it imperative that these experiments be repeated many times and scrutinized for small systematic errors. This process is still in progress but we can report the following preliminary results.

Surprisingly, the data obtained thus far shows that the effect of P impurities is to increase the enthalpic barrier to SPEG, contrary to previous assumptions. The measured increase is substantial; $\sim$ 0.2 eV for a P concentration of 5 x 10^{20} cm^{-3}, and the result apparently reliable. Since the SPEG rate typically increases tenfold for this P concentration, it would seem to be undeniable evidence that the effect is entropic. This suggests that the effect of at least this hydrogenic impurity could be to increase the vibrationally entropy of, for example, the rate-limiting interface diffusion or bond-formation. Since silicon SPEG is accelerated only by near-degenerate concentrations of substitutional hydrogenic impurities, the effect of which can be reduced or eliminated by hydrogenic charge compensation, this increase in entropy must be associated with modifications of tetrahedral covalent bonds with some long range order. It may be possible to understand these changes in terms of the bond charge model of Phillips and Van Vechten and this possibility is presently under consideration.

The initial work will lead to an M.S. degree for W.W. Park in summer 1985 and is being further pursued by two Ph.D. students at present. The results will be presented at the MRS meeting in December 1985 and in a paper being prepared for submission to Applied Physics Letters (ref).

C. FOLLOW-UP STATEMENT: We propose to continue the studies on various parts of this work unit as discussed in the progress report. In particular we propose to emphasize the studies of metal-compound semiconductor interface structure nucleation for GaAs and MCT (.8) systems. The data on GaAs systems is needed to help "read" the

experimental results in the literature. The data on MCT systems would be a major impact in the data base of metal and semiconductor system and are of technological importance. We also propose to increase our thermodynamic stability analysis efforts toward a basic understanding of metastable structure generation, as is frequently observed in reactions which are limited by internal kinetics. Even a partial understanding (for example at a level which is presently known for snowflakes) would probably significantly affect our ability to predict the direction of changes in interface nucleation and topology for parameter change in preparation or ambient conditions.

The initial research on (100) silicon SPEG is being continued at present to include the investigation of other hydrogenic impurities, particularly boron. We also plan to conduct similar experiments on partially charge compensated samples with various implanted profiles of boron and phosphorus. From the data we hope to unambiguously identify whether the effect of hydrogenic substitutional impurities on silicon SPEG is enthalpic or entropic. We also plan to investigate the effect of a few electrically inactive impurities, such as Ar and N, and non-substitutional dopant impurities, such as Pd and Co, to determine if these have different effects on SPEG than electrically active, substitutional dopants.

As mentioned in Section 2, our objective at present is to develop a thermodynamic model for the effect of impurities on SPEG. For the reasons indicated there it appears that the covalent bond charge model may provide the necessary theoretical link relating impurity induced enthalpic and entropic modifications of the long range tetrahedral bonds in silicon that, in turn, can be related to the SPEG kinetics. We are presently understanding the experimental effects of P on silicon (100) SPEG in terms of this model and will extend this modeling effort to include the effect of other impurities as those results become available.

We also plan to investigate the effect of hydrogenic, substitutional dopants on (111) silicon SPEG in the near future. We will be particularly interested to determine if some impurity can accelerate the SPEG rate on the (111) plane sufficiently to avoid the anomalous micro-twining that occurs in intrinsic (111) silicon.

D. REFERENCES

1. P. Oelhafen, J.L. Freeouf, T.S. Kuan, T.N. Jackson, and P.E. Batson, J. Vac. Sci. Technol. B1(3), 588 (1983).

2. T. Kendelewicz, W.G. Petro, S.H. Pan, M.D. Williams, I. Lindaua nd W.E. Spicer, Appl. Phys. Lett. 44(1), 113 (1984).

3. L.J. Brillson, Phys. Rev.B18(6), 2431 (1978).

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4. R.W. Bene', Appl. Phys. Lett. 41 (5), 529 (1982).

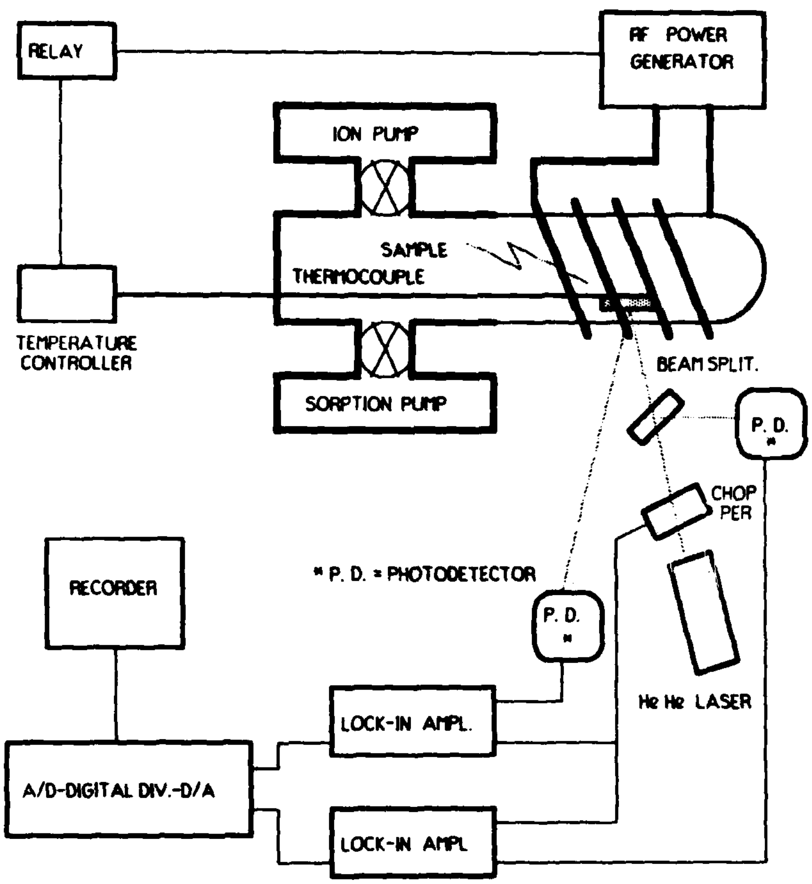

Fig. 1 In-Situ Monitoring of Recrystallization Kinetics with Laser Interferometry

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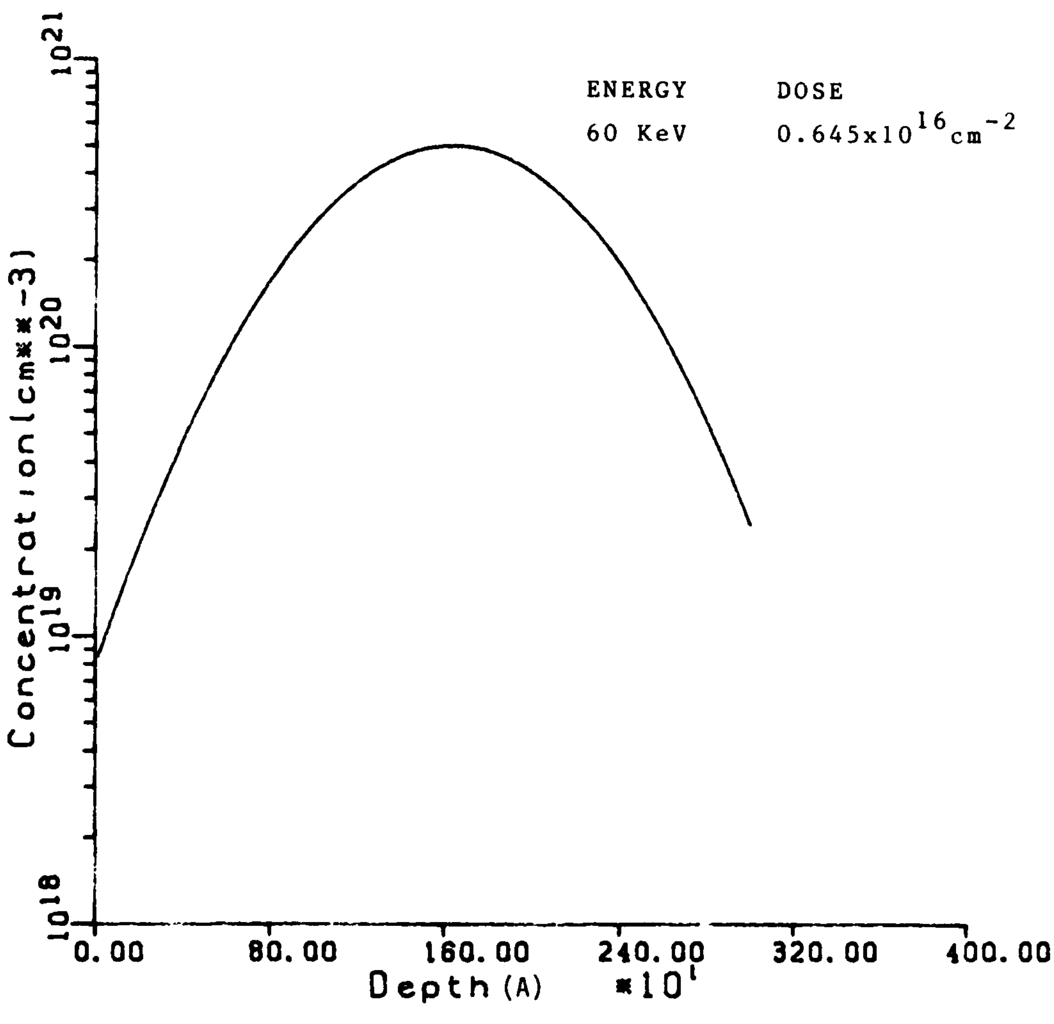

Fig. 2 Phosphorus Concentration Profile

(Page 10, Res. Unit SSE84-1, "Solid State Interface Reactions and Instabilities")

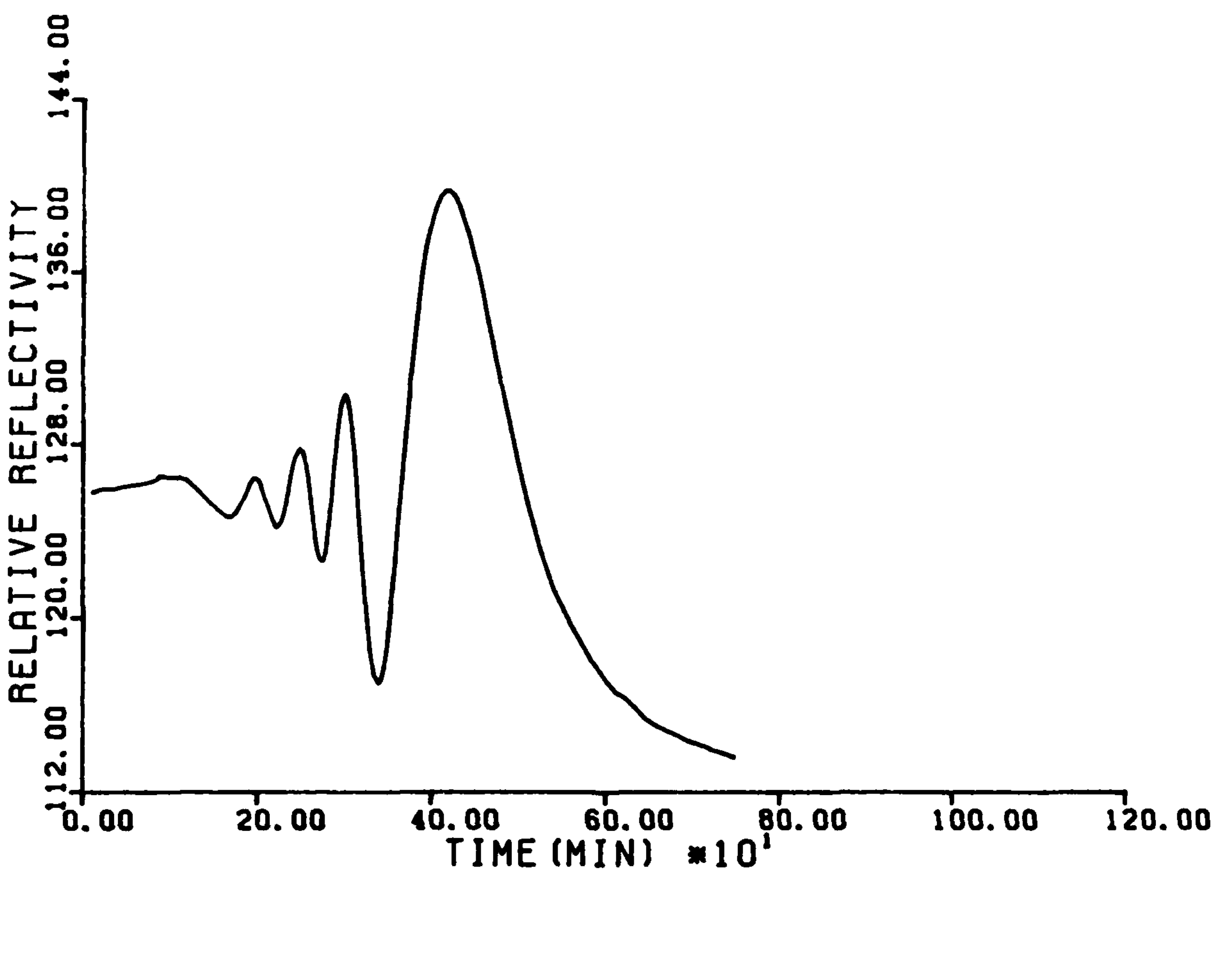

Fig. 3 Time Resolved Relative Reflectivity of Phosphorus Implanted Sample At 475°C Annealing Temperature

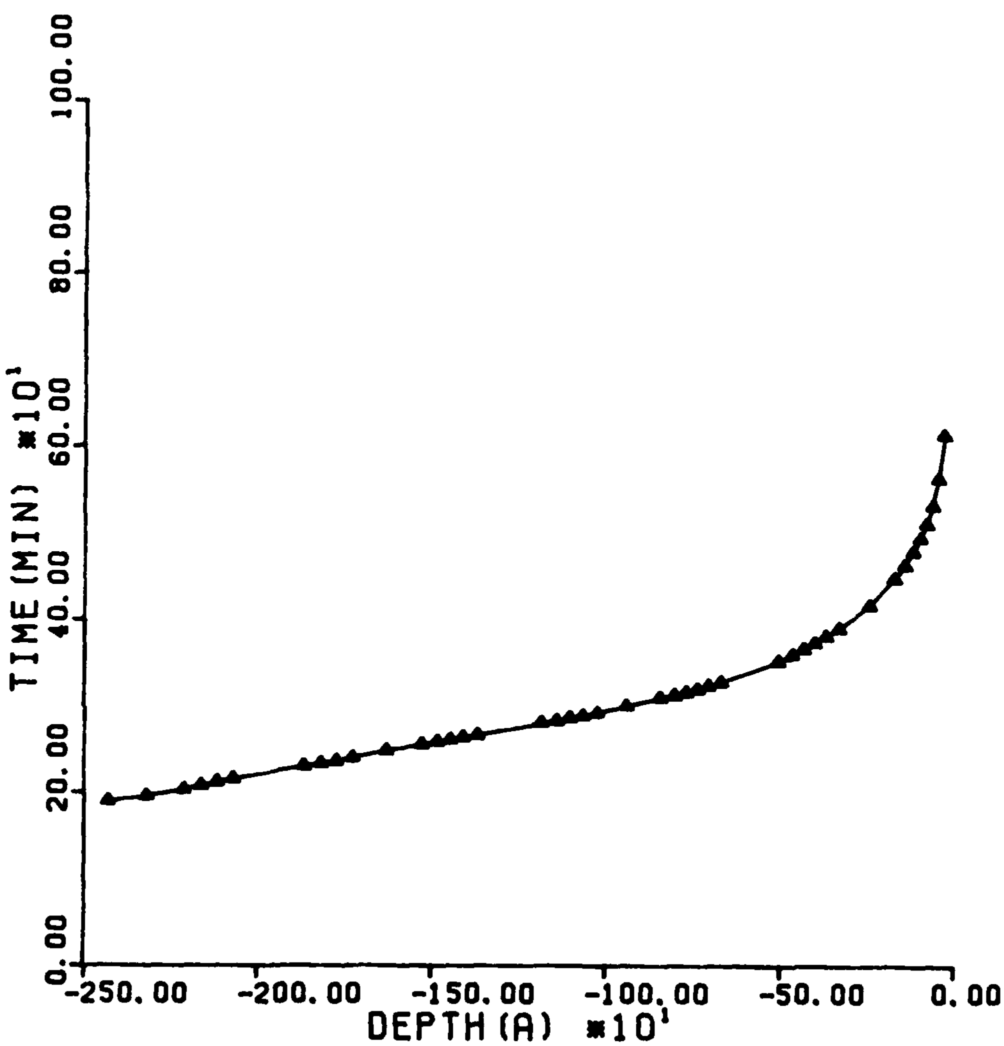

Fig. 4 Annealing Time Versus Depth of Amorphous-Crystalline Interface of Phosphorus Implanted Sample at 475°C Annealing Temperature

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE84-2 ELECTRONIC PROPERTIES AND STRUCTURE OF METAL SILICIDES AND INTERFACES

Principal Investigator: Professor J.L. Erskine (471-1464)

Graduate Student: Joe Comunale

A. OBJECTIVES: The scientific objective of this research unit is to investigate the structure and electronic properties associated with selected solid surfaces and solid state interfaces. Particular emphasis in our program during the last year has been directed toward developing new experimental probes to study surface reconstruction, and the electronic properties of reconstructed surfaces. Corresponding efforts have been directed towards setting up the required new instrumentation for studying novel surface and interface structures. Our present goal is to develop instrumentation which will enable our group to combine important new sample preparation methods such as molecular beam epitaxy (MBE) with powerful probes of electronic properties and surface structure based on electron spectroscopic techniques. This combination of sample preparation and analysis will enable us to address a broad range of new issues related to interface formation and growth of a variety of metal and semiconductor interface systems.

B. Progress

1. Metal Semiconductor Interfaces

We have studied the low coverage interaction of Ni atoms with Si(100) surfaces and have reported that it is possible to form a diffusion layer of Ni atoms in the Si lattice with novel properties [1]. We believe that the diffusion layer is characterized by Ni atoms in interstitial voids of the Si lattice, and that these Ni interstitial defects can account for selective growth processes based on a model proposed by Tu [2]. The diffusion layer is not depleted by prolonged annealing, and the stoichiometry of the layer is $NiSi_2$. Several other groups are now studying thicker films of this system using LEED [3], surface EXAFS [4] and TEM [5]. These groups also find a $NiSi_2$ stoichiometry interface, but believe that the crystal structure is the CaF_2 structure of $NiSi_2$ rather than our proposed diffusion layer structure [6,7]. The $NiSi_2$ structure has an excellent lattice match to the Si lattice substrate, but can grow in one of two rotational twin structures called type A and type B lattices. Interfaces of type A and type B yield different Schottky barrier heights [5]. We have attempted (unsuccessfully) to grow $NiSi_2$ layers sufficiently thin on Si(111) and Si(100) substrates to investigate these interesting interfaces using electron spectroscopy. Such studies using angle

resolved photoelectron emission spectroscopy will provide a direct determination of the electronic structure of the interface, and should provide important insight into the origin of the difference in Schottky barrier height for the type A and type B silicide layers. Co-evaporation of metal and silicon under precisely controlled MBE conditions should permit fabrication of the very thin silicide interfaces needed for these studies. We are currently constructing a MBE reactor coupled to an electron spectrometer which will permit such interface studies.

2. Rare Gas Atoms on Surfaces

Recent experimental [8] and theoretical [9] results suggest that the binding energy of electronic states associated with rare-gas atoms on surfaces exhibit important features which are related to the work function appropriate to microscopically small regions of a substrate. The chemical activity associated with small regions such as steps and corners, and the site specific nucleation of phases during metal deposition on semiconductor surfaces makes the determination of the local work function potentially very important. We have completed an extensive study of Xe, Ar and Kr gas physisorbed on βNiAl(110) - a crystalline alloy surface with well known stoichiometry. We have observed interesting new phenomena associated with the local surface crystal field (splitting of the excited state spectral lines) [10] and have also shown that the binding energy of the electronic states do not necessarily lead directly to an appropriate value for the average surface work function [11].

3. New Instrumentation

Ray tracing studies for our 6-meter toroidal grating monochromator are complete [12] and good progress has been made in constructing the instrument. Vacuum testing of the grating tank and evaluation of the scan drive assembly are in progress.

The final design and construction phase involving the exit slit carriage and mirror mounts is also in progress and we expect to complete the project within 9 months. This instrument will be installed at either the Aladdin storage ring at Stonghton, Wisconsin, or the NSLS facility at Brookhaven National Labs and will provide a valuable new instrumentation resource for materials science research at The University of Texas.

We have also completed a feasibility study [13] of new multichannel detection electron optics which will be used in our studies of semiconductor surfaces. A prototype analyzer is being constructed and will be tested during the next six months. If this analyzer is successful, it will revolutionize an important area of electron spectroscopy.

C. CURRENT RESEARCH: We have recently shown (under AFOSR sponsorship) that high resolution electron energy loss spectroscopy (EELS) can be used to determine the surface phonon bands throughout the two-dimensional Brillouin zone [14,15]. Surface vibrational properties are closely related to surface structure, and lattice dynamical calculations [15] permit structural models to be tested based on vibrational data. Recent theoretical studies of semiconductor surface vibrational properties suggest that surface phonon measurements can provide direct information related to the mechanisms responsible for surface reconstruction [16-18]. We are planning to apply electron scattering spectroscopy to the Si(111) and Si(100) reconstructed surfaces to investigate these predictions.

Recent experimental work using electron scattering (EELS) and photoelectron emission has indicated that the reconstructed surfaces of several semiconductors are metallic [19,20] and exhibit novel dielectric properties. One of the first experiments we plan to conduct using our new high-resolution electron spectrometer is to investigate the metallic-like states at the Fermi level of reconstructed silicon and germanium surfaces.

D. REFERENCES

1. Yu-Jeng Chang and J.L. Erskine, Phys. Rev. B26, 4766 (1982).

2. K.N. Tu, Appl. Phys. Lett. 27, 221 (1975).

3. W.S. Yang, F. Jona and P.M. Marcus, Phys. Rev. B28, 7377 (1983).

4. F. Comin, J.E. Rowe and P.H. Citrin, Phys. Rev. Lett. 51, 2402 (1983).

5. R.T. Tung, J.M. Gibson and J.M. Poate, Phys. Rev. Lett. 50, 429 (1983).

6. Yu-Jeng Chang and J.L. Erskine, Phys. Rev. B28, 5766 (1983).

7. J.L. Erskine and Yu Jeng Chang, Mat. Res. Soc. Symp. Proc. 25, 353 (1984).

8. J. Kuppers, H. Michel, F. Nitschke, K. Wandelt and G. Ertl, Surface Science 89, 361 (1979); J. Kuppers, K. Wandelt and G. Ertl, Phys. Rev. Lett. 43, 928 (1979).

9. N.D. Lang and A.R. Williams, Phys. Rev. B25, 2940 (1982).

10. M. Onellion and J.L. Erskine, Bull. Am. Phys. Soc. 30, 516 (1985); (to be published).

11. M. Onellion and J.L. Erskine (to be published).

12. Louis Breaux, M.S. Thesis, Univ. of Texas (1985), (to be published).

13. F. Hadjarab, M.S. Thesis, Univ. of Texas (1984); F. Hadjarab and J.L. Erskine, J. Electron Spectros. Rel. Phonom., in press. (Also see 15 below).

14. R.L. Strong, Ph.D. Thesis, Univ. of Texas (1984).

15. R.L. Strong and J.L. Erskine, Phys. Rev. Lett. 54, 346 (1985); Phys. Rev. B (in press); also, Technical Report: "Advanced Electron Optics for Surface Vibrational Spectroscopy", Interim Report 2, AFOSR-83-0131 (1983).

16. W. Goldammer and W. Ludwig, J. de Physique 43, C5-119 (1984).

17. W. Goldammer, W. Ludwig, W. Zieran and C. Falter, Surf. Sci. 141, 139 (1984).

18. D.C. Allan and E.J. Mele, Phys. Rev. Lett. 53, 826 (1984).

19. S.D. Kevan, (private communication).

20. B.J.N. Persson and J.E. Demuth, Phys. Rev. B30, 5968 (1984).

Research Unit SSE84-3 IMPLANTATION AND INTERFACE PROPERTIES OF InP AND RELATED COMPOUNDS

Principal Investigator: Professor Ben G. Streetman (471-1754)

Graduate Students: C. Farley, T. Kim, S. Lester and H. Shin

A. SCIENTIFIC OBJECTIVES: Several important materials properties of InP make it particularly attractive for use in high-speed field effect transistors and integrated circuits, as well as in optoelectronic systems. In terms of electron mobility and peak velocity, this material competes well with Si or GaAs. Furthermore, InP appears to be a much better material than GaAs for metal-insulator-semiconductor (MIS) field-effect transistors (FETs). However, these inherent advantages cannot be exploited in electronic devices and systems without considerable basic understanding of effects occurring during processing. This information is currently unavailable or is too incomplete to be useful in device fabrication. The objective of this research is to provide better understanding of two of the most important of these effects: (a) impurity migration and activation during various implantation and annealing procedures; and (b) formation of a clean InP-insulator interface with an acceptable density of interface states.

In the implantation and annealing studies, our objective is to develop procedures for obtaining controllable profiles of implanted donors and acceptors with good electrical activation. Since previous work has shown considerable migration of impurities during typical thermal annealing of implanted InP, some form of transient annealing is required. This study includes work on encapsulation of the InP surface during annealing. Impurity distributions are studied, along with donor or acceptor activations and interactions with background compensating impurities in semi-insulating InP material.

Surface studies include silicon oxide and nitride and layers on clean InP surfaces. The objective of this work is to develop a low interface state density, suitable for MIS device fabrication.

A final objective of this work is to employ the results learned in the fundamental studies to fabricate InP MIS transistor test structures. This portion of the work will be done primarily through collaboration with colleagues at industrial and government laboratories.

B. PROGRESS:

1. Characterization of InP Substrates

Low temperature photoluminescence (PL) was used for characterization of InP substrate materials and epitaxial layers. Fe doped

semi-insulating liquid encapsulated Czochralski (LEC) grown InP substrates were studied from five different vendors. Undoped n-type and Fe doped semi-insulating liquid phase epitaxial (LPE) layers were also characterized. Peaks attributable to common acceptors: (Be, Mg, Zn, Mn) were observed in LEC crystals, as unintentional background impurities incorporated during crystal growth. Furthermore, the LEC substrate from one vendor (Sumitomo) shows large Cu related peaks in the PL spectra after annealing. Several unidentified peaks are also observed in these PL spectra and their origins are currently being investigated.

The Fe doped samples show enhanced luminosity after annealing. This may be attributed to enhanced crystal quality, Si indiffusion from the encapsulating layer, or surface accumulation of background impurities after annealing. Our studies suggest that Fe redistribution during annealing is a factor in this enhanced luminosity. We find that capless annealing also enhances the luminosity, indicating that Si indiffusion is not the dominant effect. LPE material, which is expected to have better crystal quality than LEC material, does not show higher initial luminosity but the luminosity increases dramatically after annealing. Thus, it is reasonable to conclude that enhanced crystal quality after annealing cannot be the major reason for this enhanced luminosity. Rapid thermal annealed samples also show enhanced luminosity but to a lesser extent than furnace annealed samples. Cu related peaks also appear in the Sumitomo samples after rapid thermal annealing. These two facts support both surface accumulation of background impurities and Fe redistribution as causes of enhanced luminosity after annealing. Annealing studies of undoped InP and (PL & SIMS) profiling of annealed Fe doped InP are being performed to establish the cause of this effect.

2. Surface Studies

As a tool for removing the native oxide layer before plasma-enhanced nitride deposition, we have studied the effect of H_2 plasma etching on InP. An InP bulk crystal sample was etched by a hydrogen plasma in the plasma enhanced chemical vapor deposition (PECVD) reactor, and then a Si_3N_4 film was deposited in-situ. The sample surface was covered with micron-size agglomerates after nitride deposition. Auger depth profiling was performed to characterize the agglomerates, and a 10nm thick In-rich layer was found at the interface between the nitride and the InP. To find the chemical state of In in the In-rich layer, XPS was performed at the interface after sputtering. By calculating the Auger parameter from high-resolution XPS spectra, it was found that the In-rich layer is composed of metallic In. From these observations it appears that hydrogen plasma etching of InP produces a layer which includes metallic agglomerates which segregate into In droplets during subsequent nitride deposition.

MIS work has concentrated on the evaluation of the electrical characteristics of dielectric/InP interfaces using C-V measurements. The dielectrics studied thus far include SiO_2, Si_3N_4, phosphorus-doped SiO_2 and Si_3N_4, and sandwich structures consisting of doped and undoped layers. Two kinds of insulator structures: Si_3N_4 and P_3N_5/Si_3N_4 (PECVD deposited) were studied. The double structure was studied because preferential evaporation of P from InP is known to occur; therefore, during the early stages of the deposition, the bare InP surface is expected to lose P atoms. To produce a stoichiometric surface, a P_3N_5 layer was deposited using PH_3 and N_2 plasma. From high frequency C-V measurement it was found that an MIS structure with P_3N_5/Si_3N_4 double layer allowed more movement of surface potential than an MIS structure with only a single layer of a Si_3N_4. Insulator composition and deposition conditions and InP surface preparation techniques are presently being optimized for MIS device applications. Initial results suggest that the presence of phosphorus in the dielectric is very important, and further work will concentrate on improved and novel deposition methods and post-deposition processing leading to MISFET devices.

3. Implantation Studies

Photoluminescence data indicates that both PSG and Si_3N_4 films grown in our lab seem to work well up to 750°C as encapsulants for annealing of InP. The work on implantation has centered on the effect of P dual implants on Si activation in InP. It has been predicted that implants into InP should cause the P host atoms to recoil deeper than the In atoms, on average, since P is much lighter. Carrier concentration profiles for implants of various dopants into InP show asymmetries which could be explained by such unequal recoil of In and P. It is observed that the co-implantation of P enhances activation of the Si implant As expected from the deeper recoil of P, we observe greater enhancement for the case where the P implant is on the surface side rather than the bulk side of the Si peak. Mobilities obtained from Hall measurements are highest for the single Si implant and lowest for the shallow P co-implant, as would be expected due to the increased impurity scattering as Si becomes activated. Si implants into various types of InP substrates show varied activation efficiencies, but similar mobilities. Hall measurements at 77K show that the Si and Si+P implants freeze out substantially, but the carrier concentrations follow the trends observed at room temperature. Less freeze out is observed for the Si implants into LPE material. The mobility of the Si implants rises to $\sim$12,000 cm^2/Vs at 77K whereas the mobility of the Si+P implants rises only to $\sim$6000 cm^2/Vs.

The Hall measurements are confirmed by PL studies of these dual implants. If the donor to acceptor (DA) transition can be attributed

to the number of Si acceptors (which is reasonable since Si acceptors are present in concentrations much higher than background acceptor concentrations for the dose studied), the PL spectra confirm that the P co-implant enhances the probability that Si will act as a donor. Also the theory of unequal recoil is confirmed, since higher DA luminosity is seen for the Si implants than for the Si+P co-implants. From these results it is clear that stoichiometry is a critical determinant of implant activation in InP.

C. FOLLOW-UP STATEMENT: The work described above is part of a continuing three year program for which this is the second annual report. Work on impurity migration and activation will proceed with the investigation of thermal pulse annealing of implants using an incoherent light source. Atomic profiles of impurity distributions obtained from SIMS will be compared with electrical profiles obtained from Hall and C-V measurements. Several P-doped insulators will be studied for their ability to passivate the InP surface and provide a viable MIS structure. Depending upon the success of these studies, appropriate MIS layers will be used in simple FET structures to explore device applications.

D. REFERENCES

1. C.W. Farley and B.G. Streetman, "The Role of Defects in the Diffusion and Activation of Impurities in Ion-Implanted Semiconductors," J. Electr. Mater. 13, 401-436 (March 1984).

2. C.W. Farley and B.G. Streetman, "Simulation of Anomalous Be Diffusion in Semi-Insulating InP," J. Electrochem. Soc. 131, 946-947 (April 1984).

3. S.K. Banerjee, B. Lee, J.E. Baker, D.A. Reed and B.G. Streetman, "Annealing of Ion-Implanted Silicon-on-Insulator Films Using a Scanned Graphite Strip Heater," Thin Solid Films 115, 19-26 (May 1984).

4. S.K. Banerjee, R.Y. Tong, B. Lee, R.Y. DeJule, B.G. Streetman, and H-W. Lam, "Implantation and Annealing Studies of Laterally Seeded Recrystallized Silicon on Silicon Dioxide," J. Electrochem. Soc. 131, 1409-1416 (June 1984).

5. S.K. Banerjee and B.G. Streetman, "Planar Junctions in Silicon-on-Oxide Grown using Lateral Epitaxy by Seeded Solidification," IEEE Trans. Electron Devices, ED-32, 850-853 (April 1985).

6. S.S. Chan and B.G. Streetman, "Diffusion and Electrical Properties of Sulfur Implanted in Gallium Arsenide," submitted.

III. QUANTUM ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER, QUANTUM ELECTRONICS

Research Unit QE84-1 QUANTUM EFFECTS IN LASER INDUCED DAMAGE

Principal Investigators: Professor M.F. Becker (471-3628)
Professor R.M. Walser (471-5733)

Graduate Students: Steven Fry, Austin Huang, Yong Jee, and Y.-K. Jhee

A. RESEARCH OBJECTIVE: The major objective of this research unit is to study the mechanisms of laser induced surface damage in solids. Recent emphasis has been placed on single crystal silicon surfaces, single crystal metal surfaces, and the use of charge sensitive diagnostic techniques on all types of optical surfaces. Diagnostic techniques which probe the state of the material surface at laser intensities near the damage threshold fluence will be used to determine the nature of the precursors to multi-pulse laser damage. Such precursors have been found to include accumulation, charge emission, cleaning, hardening, and conditioning. Diagnostic techniques currently in use include the measurement of charge emission into vacuum, surface potential or work function changes on the irradiated surface, and statistical and morphological changes. The goal of this program is to determine non-destructively where a particular sample is on its life curve or where its damage threshold is at a particular time. This will perhaps be possible when the events leading to multi-pulse damage are known.

Specific projects in this area study the changes induced by laser irradiation in the surface potential or work function of metal, semiconductor, and dielectric optical surfaces; the charge emission and multi-pulse damage behavior of single crystal silicon; and the multi-pulse damage of single crystal copper, aluminum, and nickel surfaces prepared by chemical, electro-chemical, single point diamond machining methods.

B. PROGRESS:

1. Laser Induced Surface Potential Changes

Significant progress was made this year in the study of the relation of surface potential changes to laser induced surface damage. This work is carried on both at the Air Force Weapons Laboratory and at The University of Texas, and was supported in part by JSEP and in part by an AFOSR/SCEEE/RIP grant.

This is the first reported study of the relationship between surface potential and laser induced damage of insulating and semiconducting optical materials, and the first such study for metals damaged at wavelengths shorter than 10.6 microns [1]. By surface potential we simply mean the difference in work functions or the contact potential between two materials. Usually one material is employed as a refer-

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ence; stainless steel was used in this study. Surface potential is related to a number of material surface properties which may be of interest in the study of laser damage. For metals and semiconductors, surface potential is sensitive to band bending at the surface which can be related to surface preparation procedures, fixed surface states, or adsorbates. For dielectric materials, surface potential is sensitive to these same effects as well as to fixed charge either in the form of surface or volume charge distributions or even permanent electric dipole states.

Our interest in surface potential was aroused by our previous experiments utilizing charge emission into a vacuum as a diagnostic for the onset of laser damage or more importantly as a precursor to laser induced damage [2-4]. Although no charge emission was observed prior to damage in N-on-1 tests for silicon and ThF_4 thin films in these earlier experiments, all other materials, including copper mirrors and several types of oxide thin films, showed charge emission at fluences as low as 1/20 of the 1-on-1 damage threshold. The copper mirrors exhibited a reduction of emission for repeated shots to the same site (N-on-1) as one would expect in a conditioning or cleaning effect. To further complicate the situation, all of these materials showed either accumulation or hardening in N-on-1 tests. The idea of a non-contacting charge sensitive technique which could measure changes in the surface state of a sample appeared an attractive method to study these N-on-1 effects.

Previously, Porteus, et al. [1] used Auger electron imaging as a qualitative measure of laser induced changes in work function. In our experiments we have applied a different technique which is capable of giving spatially resolved quantitative maps of surface potential over the region in and around the laser interaction area. This technique utilizes what is known as a Kelvin probe or the Kelvin method to measure surface potential without making physical contact with the surface, and as such is also non-intrusive.

EXPERIMENTAL

The Kelvin method for measuring surface potential is essentially one of adjusting the dc voltage on the test capacitor formed by the sample surface and the reference electrode so as to null out ac variations in the capacitor voltage caused by physically dithering the reference electrode. In these experiments, we used a feedback technique which would adjust the dc voltage for an ac null automatically [5,6]. The probe assembly is shown in Figure 1. The probe electrode tip is 1 mm in diameter and is on a carrier which may be positioned over the laser beam axis and adjusted in spacing from the sample or may be withdrawn when laser irradiation takes place. The sample location is also mechanically controlled in order to position it to new irradiation sites and to scan the sample under the probe in a

raster pattern for measuring surface potential contours. Typical raster scans were squares of either 5 mm or 10 mm on a side. Data points were taken at 0.25 mm intervals on each row while the scan rows were separated by 0.25 mm for the small squares and 0.5mm for the large squares. The scan rate of the stepper motors was the chief factor limiting data acquisition speed. A magnetic drive is used to dither the probe at 88 Hz with a peak-to-peak amplitude of 0.1 mm. It requires a drive signal at 44 Hz of about 5W.

In operation, the probe tip is placed so that its closest approach to the sample surface is about 25 μm as viewed by a long working distance Questar microscope with a CCTV system. Since the capacitance between the probe and a grounded sample is about 0.1 pF and the capacitance with a dielectric sample 9.5 mm thick backed by a ground plane is considerably less, eliminating stray capacitance was crucial [7,8]. To do this we mounted a low input capacitance electrometer op-amp directly to the end of the probe arm. Other metallic objects were kept as far away as possible from the oscillating probe tip. As a result, the probe sensitivity to surface potential changes was less than 10 mV. This level is also of the same order as the noise level and the reproducibility of the measurements.

The feedback circuit used to automatically adjust the probe dc voltage to be equal to the surface potential is shown in Figure 2. The preamp has an ac voltage gain of 11 while the lock-in amplifier is adjusted for the maximum gain possible without oscillation with a 0.3 sec damping time. The dc output of the lock-in is fed back through a high impedance path to supply the surface potential to the probe. The dc output is also read by a digital voltmeter which was interfaced to the laboratory mini-computer used for automatic data reduction. Only the critical adjustment of setting the probe height above the sample surface was done manually. The probe was always scanned over the unirradiated site to obtain a background potential map which was later subtracted from the data to obtain the laser produced change in surface potential. The probe was next removed, the sample irradiated, and the probe returned to scan for the data. Sequences of scans over time could also be programmed in order to monitor the time decay of laser induced effects. The time needed to scan a 10 mm square was 16 minutes, and about half that for the 5 mm square.

The fundamental 1.06 μm wavelength of a Moletron Q-switched Nd:YAG laser was used at a rep rate of 10 Hz. It was focused on the sample with a 2 m focal length lens. Time and space profiles were checked regularly. The pulse length was 18 ns FWHM, and the focused spot was typically 0.39 mm in diameter at the $1/e^2$ points. The beam was scanned in both the vertical and horizontal directions with a narrow slit at the focal plane. An electromechanical shutter was used by the computer to control the irradiations. Pulse energy for every shot was recorded and statistics were computed. The standard deviation in pulse energies for 10 to 100 pulses was typically 1% or

less and never greater than 3%.

After a sequence of sites had been tested on a sample it was examined under a Normarski microscope to determine the corresponding damage morphology. Although exact damage thresholds were not measured, data was generally taken at fluences between 1/2 and 2 times threshold with an exposure of 10 or more pulses in order to attempt to observe pre-threshold as well as permanent damaging effects.

The sample set consisted of OFHC diamond turned copper mirrors, single crystal [111] silicon substrates, MgF_2 half wave (at 1.06 µm) thin films on fused silica, HfO_2 half wave thin films on fused silica, ThF_4 half wave thin films on fused silica, bare oriented crystalline MgF_2 substrates, crystalline quartz and bare fused silica substrates. The silicon and fused silica substrates used in this study were fabricated using the controlled grinding technique. Total integrated scattering (TIS) measurements on witness samples indicated an average surface roughness of 5+2A RMS for both substrate types. TIS measurements were repeated on fused silica witness substrates after film deposition. The measured surface roughness of half wave HfO_2 films on fused silica was found to be 5+1.5 A RMS. In contrast, half wave MgF_2 films on fused silica were found to have an average roughness of 10+1.5 A RMS. In subsequent examination of these samples under the Nomarski microscope, only the MgF_2 films were observed to have a definite microstructure and a "parquet tiled" appearance resulting presumably from columnar growth.

The cleaning procedure did not require touching the sample surfaces with any solid object. The samples were cleaned in a photoresist spinner with deionized water and high purity acetone and blown off with dry nitrogen. The dielectric samples were pre-cleaned by spinning on a collodion layer and subsequently lifting it off to remove any tenaciously held particulates.

RESULTS

The data in Figure 3 is for an MgF_2 thin film irradiated with 10 pulses at 69 J/cm^2. It is representative of all the thin films studied in these experiments. Note that the observed potential change is negative for this sample. Subsequent microscopic examination showed large scale damage covering the entire beam footprint. The profile of the change in surface potential was 4 to 6 mm in diameter with a magnitude of nearly half a volt. This diameter is distinctly larger than both the laser spot and the resolution of the Kelvin probe. In addition, all large scale damaging events were detected by a similar potential change. No potential changes were detected when laser damage was not observed. In these N-on-1 experiments, small damage pits were observed only on the HfO_2 film. About 50% of these small damage sites were detected by the Kelvin probe as small changes in surface potential, while the remaining sites resulted

in no observable change. The surface potential change on these thin film samples was observed to decay with time. This effect and its relation to surface charge will be discussed later.

The surface potential changes on damaged silicon and copper, although similar to each other in diameter and magnitude, were opposite in polarity. In fact, copper was the only material that showed a positive surface potential change when damaged. (Bare MgF_2 substrates also showed a positive potential change but only when bulk cracking was created by exit surface damage.)

For silicon, not all microscopically observed surface damage could be detected by the Kelvin probe. When pits were formed, indicating a more severe degree of damage, the potential changed. However, when only melting and resolidification occurred with the accompanying formation of ripples or ridges, no change in surface potential could be observed. No pre-damage changes in surface potential were ever detected.

The OFHC diamond turned copper was always observed to damage by melt pit formation, and these pits were detected by their accompanying changes in surface potential. As for the silicon, the observed diameter was limited by the 1 mm resolution of the Kelvin probe tip. One case of pre-damage change in the surface potential was observed for copper. In three other cases near the threshold fluence where no observable surface damage occurred, no surface potential change could be detected.

The surface potential change for the conductive samples was found to be constant and reproducable over time. In this case, no decaying component was observed as was for the dielectric samples.

The bare dielectric substrates seemed to be more unpredictable in their behavior. Experimental difficulty was experienced due to their tendency to damage on the exit surface. In N-on-1 experiments for large enought N, damage would propagate from the rear to the front surface before surface damage was initiated on the front surface. Experiments were thus limited to less than 10-20 pulses per site.

Both fused silica and the polycrystalline MgF_2 substrates showed similar behavior. The surface potential change was 4 to 6 mm in diameter but smaller in magnitude than for the thin films. The Kelvin probe noise level seemed to increase in the vicinity of the damage sites.

Microscopy of the damage sites on the bare substrates showed less distinct damage features which resembled surface erosion. Larger diameter surface damage sites were detected by the Kelvin probe while several smaller diameter damage sites and all undamaged sites showed no surface potential change. These surface potential changes were observed to decay with time just like those for the thin film samples, and will be discussed later.

The MgF_2 substrates showed unusual behavior when a crack from the rear surface propagated to the front. The arrival of the crack at the front surface would be accompanied by a sudden strong positive change in the surface potential. This change may be associated with the piezoelectric properties of the material or with the exoemission of electrons from the crack which leaves the substrate positively charged [9].

DISCUSSION

One of the most interesting and unexpected findings in these experiments was the significance of surface charge effects on the dielectric samples. First it will be necessary to relate the surface potential measurements to surface charge density. In measuring contact potential as between two conducting samples, the Kelvin probe separation from the surface does not affect the potential difference so long as the increase in distance can be compensated for by an increase in the gain in the feedback loop. The case of free charge on the surface of a dielectric material is entirely different. It resembles very closely the case of fixed charge in a Shottky or MOS device. The potential required to place an equal and opposite charge on the probe tip is now dependent on the tip to surface distance. The surface potential is related to the surface charge density (ignoring fringing field effects) by the parallel plate capacitor formula:

$$Q_s/A = \epsilon_0 V/d \tag{1}$$

where Q_s is the total surface charge under the probe, V is the surface potential, and d is the mean probe height over the surface. Typically, d was 70 μm so that a charge density of 1.26×10^{-11} C/cm^2 per volt of potential change was measured in these experiments. As an example, a spot 4 mm in diameter with a potential change of 0.1 V would represent about 1.3×10^6 negative charges. A rather large amount of charge is spread from the 1/3 mm diameter laser damage site to a distance of several mm.

Closer analysis of the surface potential contour maps reveals that the effect is even more widespread. The shape of the potential change peak is flat topped with a sharp drop at a diameter of 4 to 6 mm. The drop is not to zero however, since there is about 10% remaining change in surface potential which decreases slowly with distance for another several mm. This might lead an investigator to rethink the problem of site spacing for laser damage experiments on dielectric samples. The charge related effects of a damaging event extend across the sample surface much further than would be expected from either the observed damage morphology or even the incident beam diameter.

Detailed measurements of the surface potential decay as a function of time were made on the HfO_2 thin film and on the MgF_2 bare substrate. The results for the two were similar and the thin film data will be presented in detail. The potential change is observed to decay without significant migration of the charge. Presumably recombination, not diffusion, is responsible for the decay. It is not certain whether the recombination charge comes from the air or the material; however, these sites could be discharged artificially with airborne charge by using a static charge gun or by creating another charge cloud from a nearby laser damage site.

The decay of the surface potential peak values obtained from the scans is plotted in Figure 4. From the simple linear graph, we infer a single exponential decay process with a time constant of 62 min. The decay asymptote is not zero potential change. There is permanent damage, and some fixed change is expected. In this case the fixed part of the potential change is -25 mV as compared to the initial peak of -100 mV. As indicated previously, similar data was obtained for the MgF_2 bare substrate for which a 30 min time constant was observed.

Obviously no such free charge effects will be observed for conductive samples. An earlier study using Auger analysis of damage sites on OFHC copper surfaces demonstrated the effects of surface shape changes (pit formation) on the work function [1]. We also observed these effects on copper with 1.06 m illumination. There is no way of telling if the sign of the change observed by the authors of reference [1] matches that measured by the Kelvin probe since they used a different method which measured only qualitative potential changes. Similar potential changes were observed at damage pits on silicon but of opposite polarity. There is no obvious reason why such a polarity difference should exist.

One of the objectives for undertaking these experiments was to observe sub-damage threshold changes in the surface potential on those materials which emitted charge at 1/10 to 1/20 of the threshold fluence, or showed accumulation or cleaning effects. In this respect we were unsuccessful. One possible pre-threshold event was observed for copper out of four total observations. If a subthreshold surface potential effect exists, it is not large.

CONCLUSIONS

We observed distinct surface potential signatures associated with laser damage. For conductors, silicon and OFHC copper, small diameter surface potential changes were detected in conjunction with pit formation. No surface potential change was seen on silicon when only surface ripples or ridges formed. Copper differed from silicon and all other materials in that the sign of the surface potential change was positive.

All of the insulating materials showed surprisingly large diameter surface potential changes around the laser damage spots. These potential changes were observed to extend over an area 4 to 6 mm in diameter as compared to the 1 mm diameter Kelvin probe resolution and the 1/3 mm laser beam spot diameter. These charged areas contained as many as 10^7 negative charges. In light of this large diameter charging effect, the spacing of adjacent sites in laser damage experiments on insulating substrates and thin films should be carefully reexamined.

The charge on the insulators' surfaces was observed to decay with time constants on the order of an hour to a constant level whose value is 1/4 or less of the initial value. We associated this change with recombination, and the fixed change in potential with the effect of surface geometry and damage morphology on surface potential.

No consistent pre-damage potential changes were observed indicating that the charge emission and surface cleaning observed in previous experiments do not have a significant effect on surface potential. Evidently these effects are not appropriate for study by surface potential methods.

This work on surface potential has been published in two conference proceedings [10,11].

2. CHARGE EMISSION FROM SILICON

The study of the relation between multi-pulse laser damage of silicon at 1.06 μm and the emission of charge into vacuum was completed last year. A technical description of this work which appeared in last year's JSEP annual report has since been published [12-13], and formed the basis for Y.K. Jhee's Ph.D. dissertation.

3. DAMAGE OF SINGLE CRYSTAL METALS

In the study of the damage behavior of single crystal metals at 1.06 μm we have completed the sample finishing and characterization phase of the project and started preliminary multi-pulse damage testing. In a joint project with the Los Alamos Scientific Laboratory single point diamond machining was done on various crystallographic faces of copper, aluminum, and nickel samples. Subsequent x-ray and electron channelling analyses of these samples indicate good single crystal properties in the bulk and the presence of a distorted lattice layer near the surface due to the machining process. The samples were prepared using a geometrically decreasing series of cut depths so as to minimize surface distortion and have a uniformly controlled finishing process.

Chemical and electro-chemical finishing procedures have been developed for copper and aluminum. Both of these processes leave the samples in an undisturbed single crystal state as observed by both

x-ray and electron channelling analysis. The electro-chemically polished samples were produced in cooperation with the Naval Weapons Center, and the chemically polished samples were prepared in our laboratory.

Preliminary damage testing has revealed that all the samples undergo an accumulation-like decrease in damage threshold for increasing numbers of pulses at the same site. To date, only the copper samples, prepared by any of the three preparation methods, show damage thresholds as high as would be predicted by a calculation of the melt threshold based on a heat flow model.

C. FOLLOW-UP: New basic studies of the accumulation effect in single crystal silicon will continue in the coming year. An experiment to determine the annealing decay rate of accumulation has been initiated.

The previous study of charge emission from silicon as well as the work on the correlation of surface potential changes with laser damages are now complete.

Multi-pulse damage testing of the single crystal metal sample set will continue.

REFERENCES

1. J.O. Porteus, D.L. Decker, D.J. Grandjean, S.C. Seitel, and W.N. Faith, "Defect-Damage Resistant Copper Mirrors," in 11th ASTM Symposium on Optical Materials for High Power Lasers, NSB Special Publication #568, Boulder, CO (1979).

2. M.F. Becker, F.E. Domann, A.F. Stewart and A.H. Guenther, "Charge Emission and Related Precursor Events Associated with Laser Damage," 15th ASTM Symposium on Materials for High Power Lasers, NBS Special Publication, Boulder, CO (1984).

3. J.K. Jhee, M.F. Becker, and R.M. Walser, "Charge Emission and Accumulation in Multiple-Pulse Damage of Silicon," 16th ASTM Symposium on Materials for High Power Lasers (elsewhere in these proceedings), NBS Special Publication, Boulder, CO (1985).

4. M.F. Becker, H.K. Jhee, M. Bordelon and R.M. Walser, "Charged Particle Excemission from Silicon During Multi-Pulse Laser Induced Damage," 14th ASTM Symposium on Optical Materials for High Energy Lasers, NBS Special Publication #669, Boulder, CO (1983).

5. Y. Petit-Clerc and J.D. Carette, "New Feedback Kelvin Probe," Rev. Sci. Inst. 39, 933 (1968).

6. J.C. Campuzano and R.G. Greenler, "Instrument for Combining Reflection-Absorption Infrared Spectroscopy with other Surface-Sensitive Techniques," Rev. Sci. Inst. 52, 678 (1981).

7. R.J. D'Arcy and N.A. Surplice, "The Effects of Stray Capacitance on the Kelvin Method for Measuring Contact Potential Difference," J. Phys. D: Appl. Phys. 3, 482 (1970).

8. N.A. Surplice and R.J. D'Arcy, "A Critique of the Kelvin Method of Measuring Work Function," J. Phys. E: Sic. Inst. 3, 477 (1970).

9. P. Braunlich, "Exoelectron Emission from Optical Surfaces," 2nd ASTM Symposium: Damage in Laser Materials, NBS Special Publication #341, Washington, DC (1970).

10. M.F. Becker, J.A. Kardach, A.F. Stewart and A.H. Guenther, "Surface Potential as a Laser Damage Diagnostic," 16th ASTM Laser Damage Symposium, NBS Special Publication, Boulder, CO (1985).

11. M.F. Becker, J.A. Kardach, A.F. Stewart and A.H. Guenther, "Surface Potential as a Laser Damage Diagnostic," Proceedings of the Southwest Conference on Optics, SPIE, Bellingham, WA (1985).

12. M.F. Becker, Y.-K. Jhee and R.M. Walser, "Charge Emission and Accumulation in Multiple-Pulse Damage of Silicon," 16th ASTM Laser Damage Symposium, NBS Special Publication, Boulder, CO (1985).

13. Y.K. Jhee, M.F. Becker and R.M. Walser, "Charge Emission and Precursor Accumulation in the Multiple-Pulse Damage Regime of Silicon," accepted for publication by the Journal of the Optical Society of America, Part B.

(Page 11, Res. Unit QE84-1, "Quantum Effects in Laser Induced Damage")

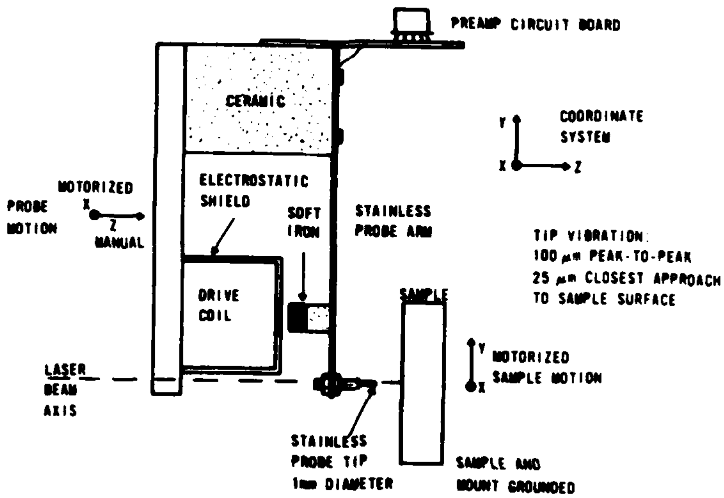

Figure 1 Mechanical diagram of the Kelvin probe.

KELVIN PROBE INSTRUMENTATION

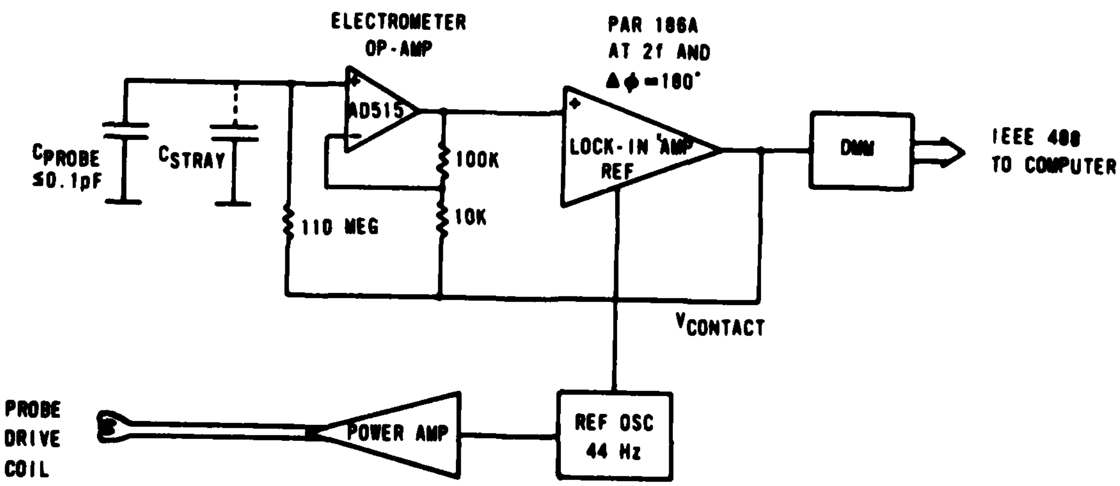

Figure 2 Schematic diagram of the Kelvin probe instrumentation.

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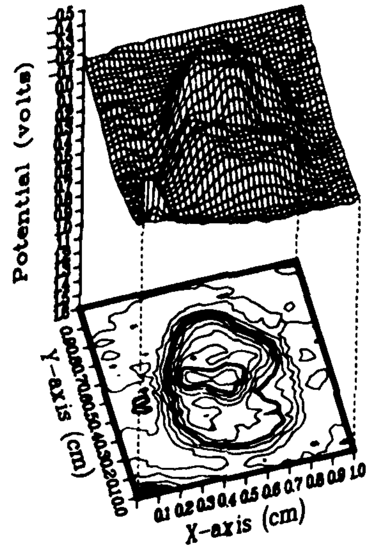

Figure 3 Surface potential change contour plot for the MgF_2 thin film irradiated by 10 pulses at 69 J/cm^2. The format is discussed further in the text.

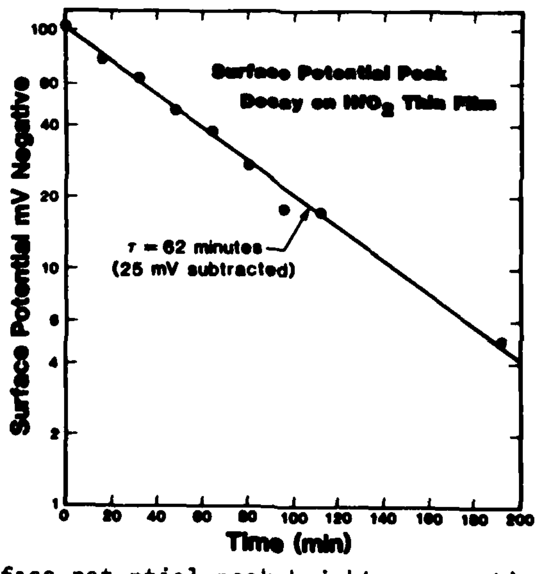

Figure 4 Surface potential peak height versus time for the HfO_2 film. The constant -25mV has been subtracted since it is the asymptotic value for the exponential decay.

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER QUANTUM ELECTRONICS

Research Unit QE84-2 NONLINEAR RAMAN SCATTERING FROM MOLECULAR IONS

Principal Investigator: Professor J.W. Keto (471-4151)

Graduate Students: Norbert Boewering, Mike Bruce and John Sample

A. RESEARCH OBJECTIVES: The primary objective of this research unit is the development of coherent antistokes Raman scattering (CARS) or stimulated Raman gain spectroscopy for studies of reactions and structure of cluster ions formed at high pressures.

Research on the reactions and structure of ions at pressures near or above atmosphere is relatively new. Such studies have been motivated by electron beam driven or preionized lasers [1,2], particle beam weapons [3] and plasma chemistry [4]. To date most studies of ion-molecule reactions and recombination of positive ions with electrons or negative ions have been done at pressures up to 10 Torr. In part the restriction to low pressures has been intentional as the desire has been to understand the quantum mechanics for the interaction of two free particles. In general it is thought that when fundamental two-body interactions are understood, they can be used to model the more complicated systems.

Three-body collisions are known to be required in association reactions

$$A + B + X \rightarrow AB + X \tag{1}$$

where the third body relaxes the pair into a stable state by carrying away extra kinetic energy. In estimating the formation rates of cluster ions, Smirnov [5] has described several models for estimating three-body (termolecular) reaction rates. Though the importance of termolecular reactions for association of particles has long been known, it remains common for workers to assume that if bimolecular reactions are dominant at lower pressures that they continue to dominate at higher pressures. Hence dissociative recombination rates or charge transfer rates measured at low pressures are applied to models of discharges at higher pressures.

In previous units studying molecular reactions, we were motivated to understand the chemistry of excimer lasers; and in those studies found that both charge transfer [6] and recombination [7] was termolecular. However, our studies of ion-molecule reactions at high pressures were greatly hampered by the lack of a probe which can distinguish the ion type. For unambiguous studies it is necessary first to develop a selective probe applicable in high pressure discharges.

The probes for such studies must have high sensitivity, and good spectral and temporal resolution. Temporal resolution is required so that the decay rates can be used to measure reaction rates. We are

interested in reactions such as association, recombination, and charge transfer. Nonlinear optical probes based on coherent Raman scattering processes when used in conjunction with high power pulsed lasers potentially meet all these criteria. Two techniques currently under consideration are coherent antistokes resonant Raman spectroscopy and gain modulated Raman spectroscopy. The spectral and temporal characteristics of these techniques are governed by the characteristics of the lasers employed. A major objective of this research unit is to demonstrate experimentally that such probes have the necessary sensitivity to detect molecular ions. When successful, these experiments will obtain the first Raman spectra of molecular ions and will greatly aid in the understanding of polyatomic molecules and high pressure discharges.

2 Polyatomic ions of interest include Xe^+, Ar^+ and Xe_nCl^+ which are relevant to excimer lasers. Other molecular ions for which there exists a need for experimental analysis include those formed in atmospheric discharges; H^+, N^+, N^+, O^+ and O^+ all fall into this category. The results from such studies will be applicable to the problem of particle beam transport in the atmosphere. Of particular fundamental interest is H^+ which is the simplest nonlinear polyatomic molecule. Data gathered on it may be compared directly to ab initio calculations [8].

B. <u>PROGRESS</u> Currently in our laboratory we are able to obtain high quality stimulated Raman gain spectra (SRGS) of liquids with the experimental setup shown in Fig. I. In this technique, a single photo diode is used to sample the beam before and after the medium using suitable optical and electronic delays. A typical spectrum of the 459 cm^{-1} vibrational line of CCl_4 is presented in Fig. 2. The several peaks seen are due to various isotopes of chlorine.

The signal to noise ratio is now improved by about an order of magnitude in comparison to our previous spectra of the 992 cm^{-1} line of benzene, obtained with a differential amplifier. Fluctuations in the integrated error are about one part in 10^4, which seems to be the limit of this technique.

Extensive studies of the propagation of laser pulses in optical fibers have been done to investigate the limitations of this technique. We came to the conclusion that our present technique is limited by fluctuations in the bandwidth of the optical fiber. This can be clearly seen by comparing Figs. 3 and 4, which show the standard deviation from an average laser pulse shape, before and after passing 100 feet of optical fiber, respectively. The laser pulses were recorded with a fast transient digitizer.

Dramatic improvements in sensitivity are possible by combining our fiber technique with the highly advantageous polarization techniques of coherent Raman spectroscopy which utilize definite input and output polarizations. The main limitation of a traditional

polarization experiment is due to stress induced-birefringence [9] in the optical components of the system. A schematic illustration of this novel experiment is shown in Fig. 5. Light from a tunable pump laser of frequency ω_2 is linearly polarized 45^0 with respect to the probe beam. The probe laser has a fixed frequency and is highly linearly polarized to approximately one part in 10^7. The best available Glan-Thomson polarizers are of such quality. In Fig. 5, the sample is indicated by SC and the analyzing polarizer by GT2 which is oriented to reject the probe component $E_y(\omega_1)$ while transmitting the signal $E_x(\omega_1)$. The overall background due to birefringence would normally be the limitation of this experiment. However, this background can be subtracted from the signal with an accuracy 10^{-4} by sampling the probe beam before and after the medium, using our fiber technique. So our overall sensitivity improves more than three orders of magnitude in comparison to the previous result. We feel that this kind of experiment might represent a breakthrough in nonlinear Raman spectroscopy. We estimate that with our N_2 pump laser we will be able to measure Raman gains to at least one part in 10^7. We note that this technique is suitable for measurement of depolarized Raman lines only. As our first try, we are preparing to measure the vibrational-rotational lines of argon dimers since state of the art calculation of energy levels and Raman cross section exist [10].

C. FOLLOW-UP STATEMENT: This work is continuing under joint services support. We feel we have made significant progress, and with planned improvements will have made a significant breakthrough in the sensitivity in coherent Raman spectroscopy.

D. REFERENCES

1. C.A. Brau, Excimer Lasers, C.K. Rhodes, Ed., Springer-Verlag, Berlin (1979).

2. C.W. Werner, E.V. George, P.W. Hoff and C.K. Rhodes, IEEE J. Q. Elect., QE-13, 769 (1977).

3. J. Parmentola and K. Tsispis, Sci. Amer., 240, 54-65 (1979).

4. A.T. Bell, "The Interface Between Plasma Physics and Plasma Chemistry," Workshop on Plasma Chemistry and Excited State Reactions, 32nd Annual Gaseous Electronics Conference (1979).

5. B.M. Smirnov, "Cluster Ions in Gases," Sov. Phys. Usp. 20, 119 (1977).

(Page 4, Res. Unit QE84-2, "Nonlinear Raman Scattering From Molecular Ions")

6. J.W. Keto, C.F. Hart and Chien-Yu Kuo, "Electron Beam Excited Mixtures of Argon Doped with O_2: I. Spectroscopy", J. Chem. Phys 74, 4450 (1981); J.W. Keto, "Electron Beam Excited Mixtures of Argon Doped with O_2: II. Electron Distribution Functions and Excitation Rates", J. Chem. Phys 74, 4445 (1981); J.W. Keto, C.F. Hart, and Chien-Yu Kuo, "Electron Beam Excited Mixtures of Argon Doped with O_2: III. Energy Transfer Reactions," J. Chem. Phys. 74, 4450 (1981).

7. Chien-Yu Kuo and J.W. Keto, "Dissociative Recombination in Electron-beam Excited Argon at High Pressures," J. Chem. Phys. 78, 1951 (1983).

8. G.D. Carney and R.N. Porter, "H_3^+: Ab Initio Calculation of the Vibrational Spectrum," J. Chem. Phys. 65, 3547 (1976); "Ab Initio Prediction of the Rotation-Vibration Spectrum of H_3 and D_3", Phys. Rev. Lett. 45, 537 (1980).

9. Marc D. Levenson, "Polarization Techniques in Coherent Raman Spectroscopy," J. Raman Spectrosc. 10, 9 (1981).

10. J. Borysow, unpublished calculations.

(Page 5, Res. Unit QE84-2, "Nonlinear Raman Scattering From Molecular Ions")

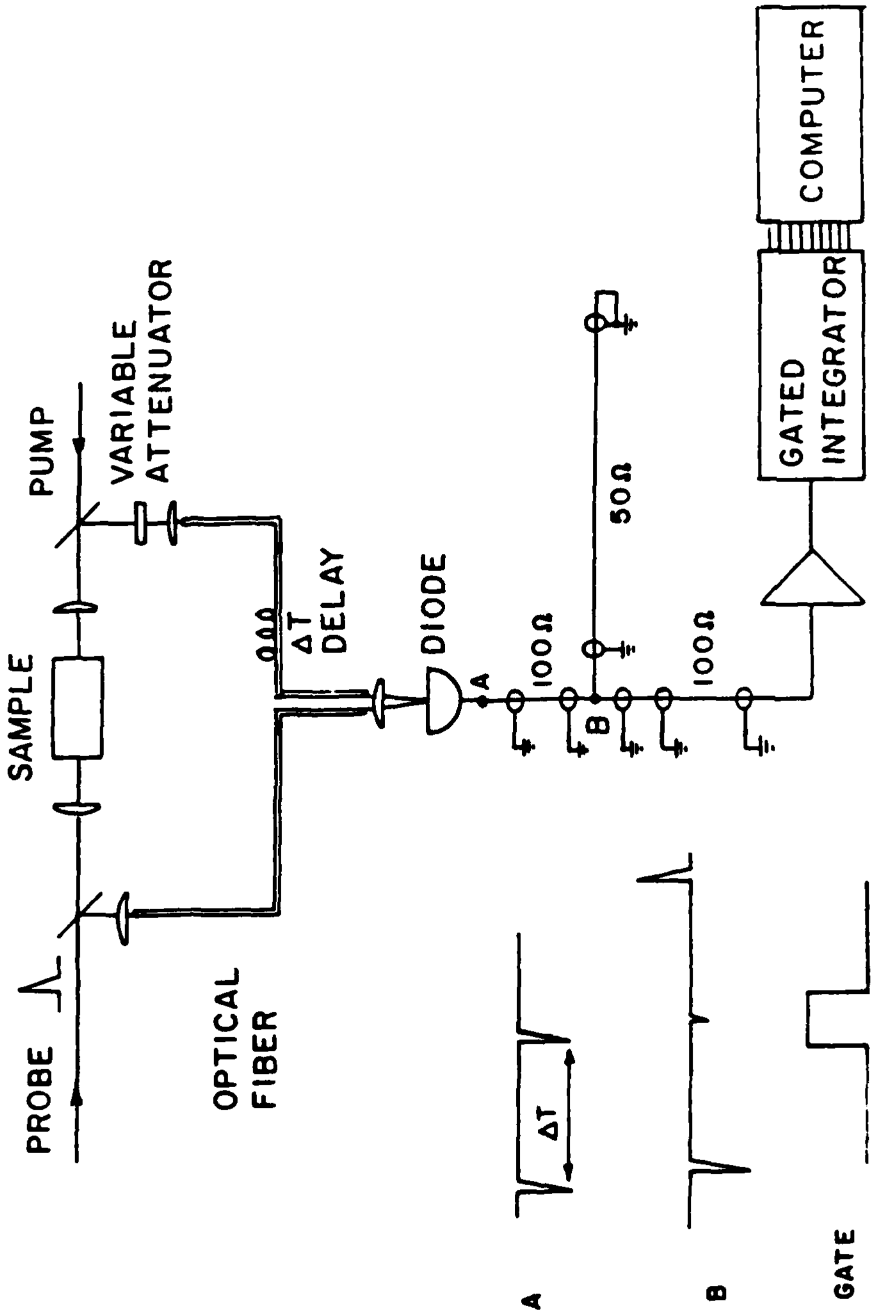

Fig. 1 SRGS apparatus using only a single photodetector to measure the probe laser gain.

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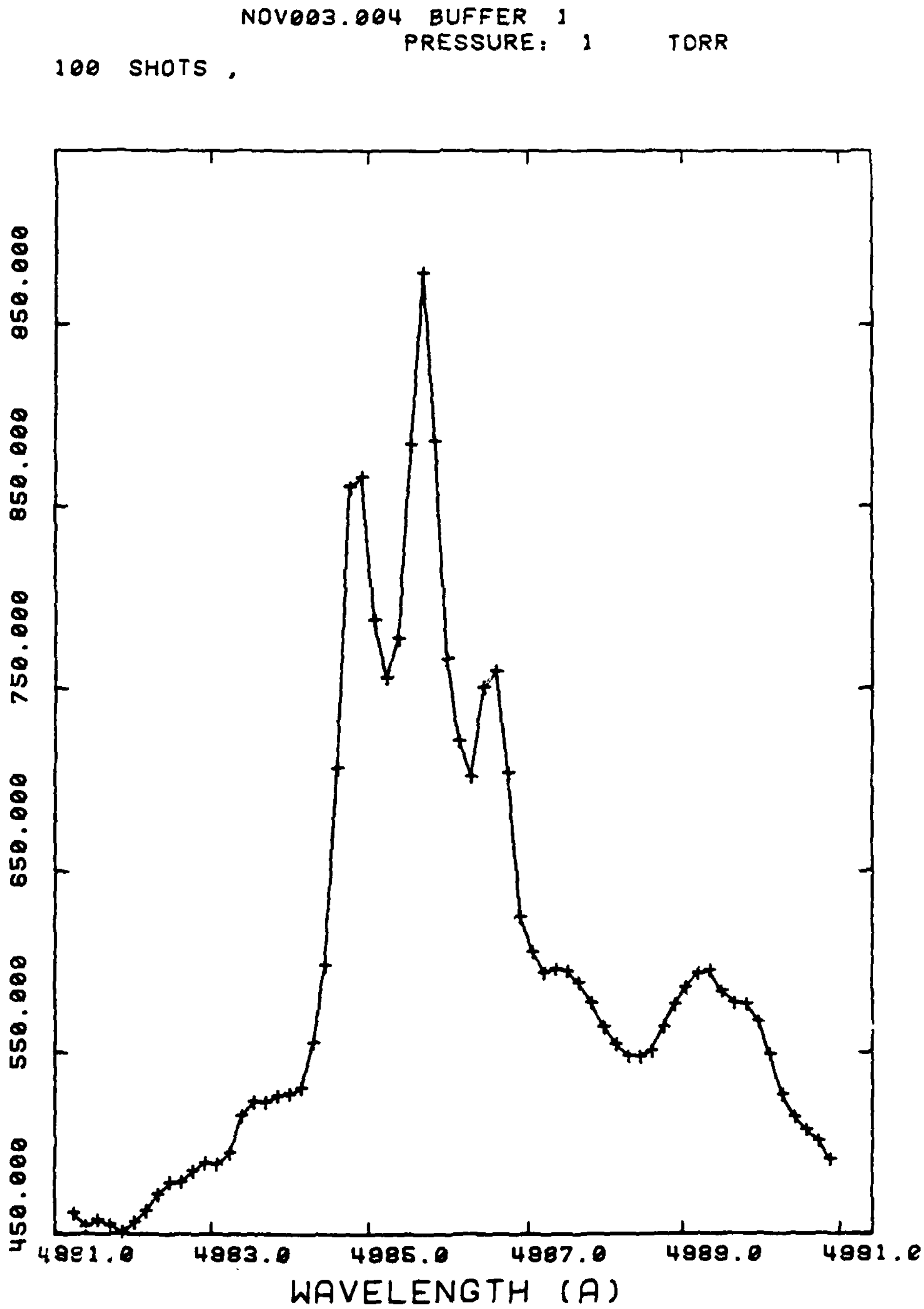

Fig. 2 Raman induced gain at 459 cm^{-1} vibrational ine of CCl_4.

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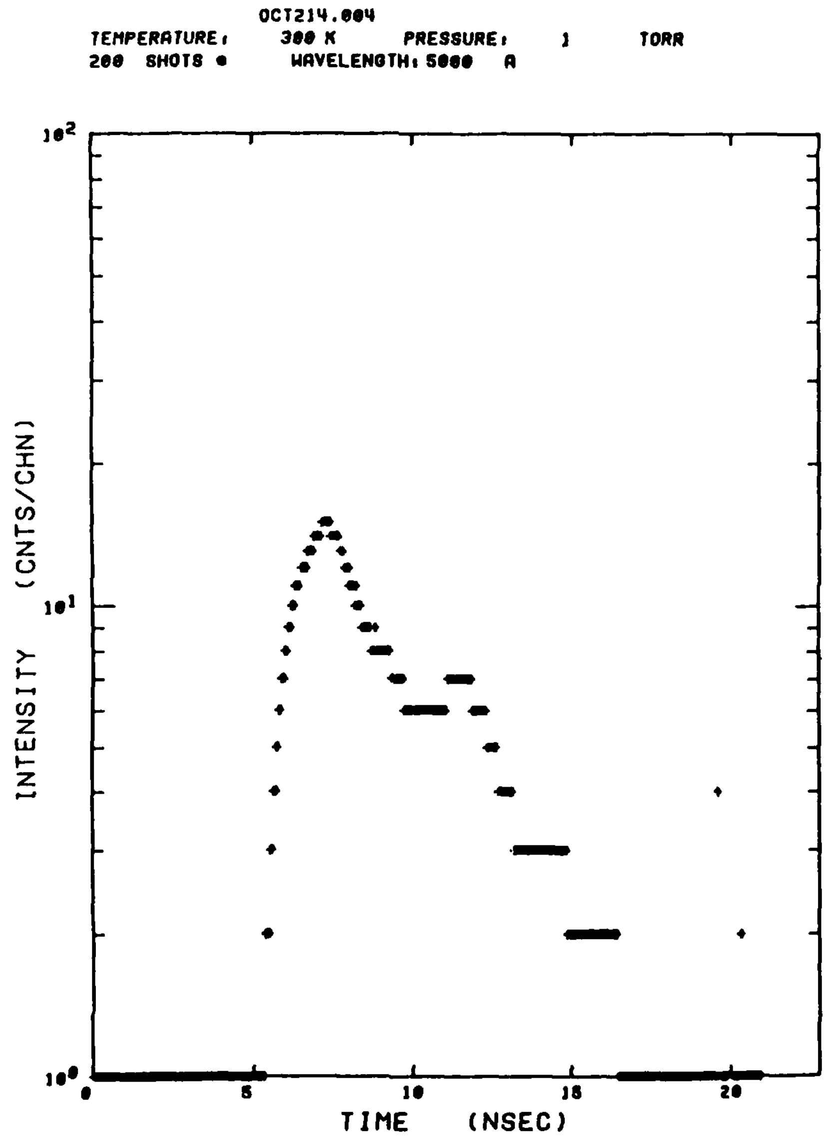

Fig. 3 Standard deviation from an average laser pulse shape.

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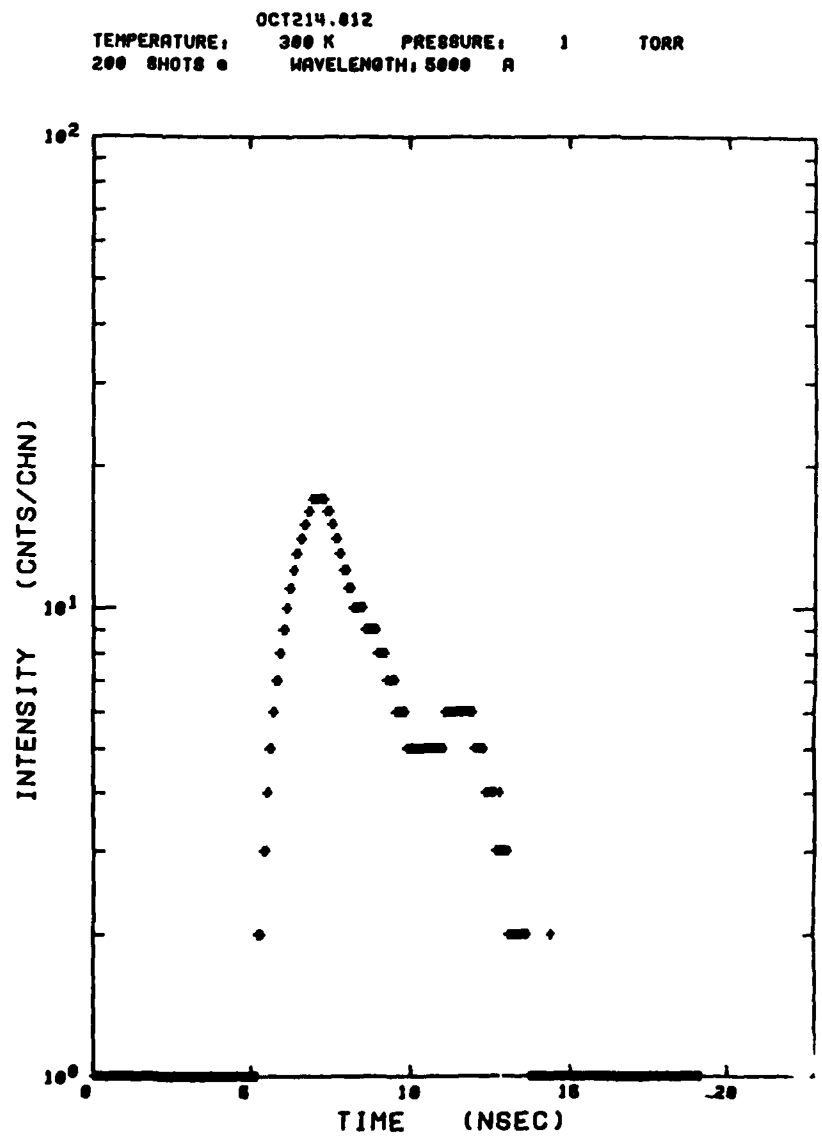

Fig. 4 Standard deviation from an average laser pulse shape after passing 100 feet of optical fiber.

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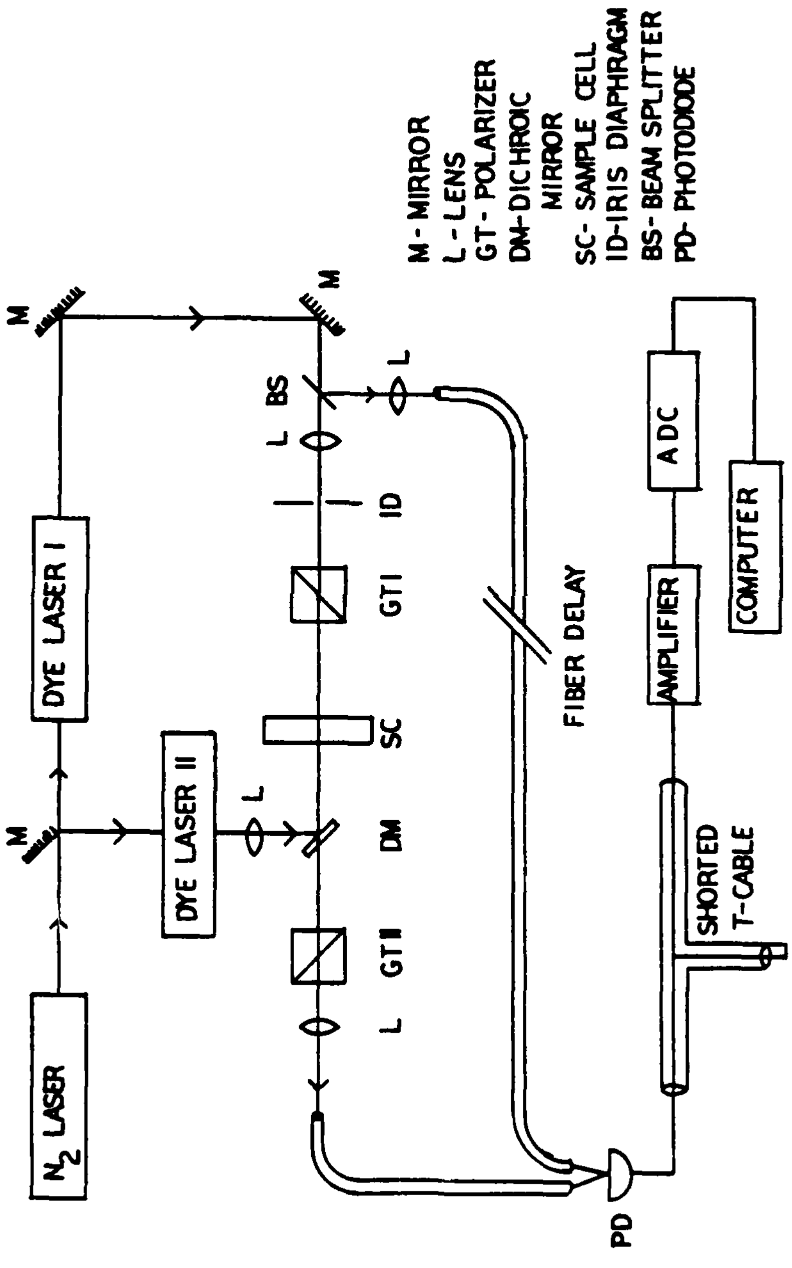

Fig. 5 SRGS apparatus with polarizers using a single photodetector to measure depolarized probe laser gain.

THE UNIVERSITY OF TEXAS AT AUSTIN — Electronics Research Center, Quantum Electronics

Research Unit QE84-3 NONLINEAR OPTICAL INTERACTIONS

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Graduate Students: Tim Boyd, Dan Coffman, S. Ketkar, R. Mawhorter, L.A. Orozco, and Ling-An Wu

A. <u>SCIENTIFIC OBJECTIVES</u>: This research unit is work proposed by Drs. Kimble and Fink and deals with the interaction of atoms and molecules with resonant optical fields. The emphasis of the program is many fold: (1) to study the instabilities inherent in the nonlinear coupling of a collection of atoms to the electromagnetic field in the presence of feedback (as provided for example by an optical resonator), (2) to investigate circumstances in which microscopic quantum fluctuations can lead to macroscopic effects, (3) to measure the dynamic response of a single-mode, high power CW dye laser of the Michelson type to intracavity doubling when the UV itself is trapped in a resonance cavity of its own, (4) to test the influence of laser power and polarization on resonant and near resonant optical pumping of gas jets with the intent of efficiently producing aligned samples and (5) to understand the effect of very weak magnetic and electric fields on the selection rules and the coherence of magnetic hyperfine states. The general spirit of the work might be summarized by a statement such as "The investigation of nonequilibrium phase transitions in optical systems" (the laser is an example of such a transition).

Within this general context, part of the research program that has been initiated deals specifically with the phenomena of optical bistability and optical pumping. An optical system is termed bistable if, for a given value of input field, the output of the system can be multivalued. The actual output is determined by the position of the bistable device along a hysteresis cycle. In our experiments particular emphasis is placed upon the study of a "simple" system -- that is to say, a physical system which is on the one hand experimentally realizable while on the other hand is amenable to detailed microscopic analysis. Our experiments investigate bistability for a collection of "two-level" atoms (ground state and one excited state only) inside a high finesse optical resonator. In this arrangement the cooperative interaction of atoms with the electromagnetic field is free from certain "complicating" features such as collisions, degeneracies, or Doppler shifts. Our experiments thus make direct contact with an extensive theoretical literature [5] and provide a benchmark for the understanding of bistable systems in general.

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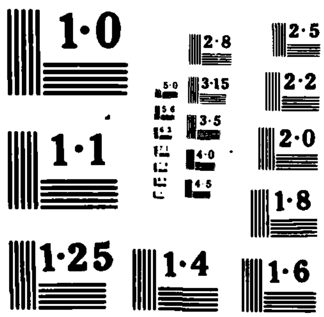
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These same comments apply to the interaction of multilevel atomic systems with resonant laser radiation. We propose to extend the understanding of optical pumping processes among nearly degenerate Zeeman and closely spaced atomic hyperfine levels. While rate equations provide an adequate description in many circumstances, in some cases of practical importance one must deal with the full density matrix of diagonal and off-diagonal elements (level to level coherence). Our goal is to explore the existing theory [23] and to apply this theory to realistic experimental conditions to produce aligned atomic ground or excited states.

The research program and its objectives that we propose for the coming years are discussed briefly and listed below.

(a) Characterization of the steady-states in optical bistability and the study of the stability of these states against external perturbations.

(b) Study of the fluctuations in bistability that arise from the quantum nature of the atom-field coupling.

(c) Investigation of dynamical behavior in bistability through measurements of transient response (i.e., switching characteristics).

(d) Exploration of instabilities in optical bistability leading to oscillatory or self-pulsing behavior.

(e) Optimization of optical pumping processes with respect to occupation numbers, state orientation and alignment.

(f) Influence of very weak magnetic and/or electric fields on fixing the underlying symmetry of optical interactions.

(g) Study of efficient intracavity U.V. generation with emphasis placed upon possible dynamical behavior.

B. <u>PROGRESS</u>: We report here on progress in three of the seven areas outlined above: characterization of steady states in optical bistability, exploration of instabilities in optical bistability and study of efficient intracavity second harmonic generation. Results of some additional related work are also reported.

Our experiment in optical bistability with two-level atoms, described in the last two annual reports, has reached a high level of maturity. Continuous (cw) light from a frequency-stable dye laser is injected into an optical resonator of very high finesse, enhancing the intensity many times. The light in the resonator interacts with a set of ten atomic sodium beams which are prepared as homogeneously broadened two-level atoms by collimation and optical prepumping. We

monitor the atomic density (which together with the resonator finesse gives us the cooperativity parameter C), the input and output intensities Y and X, and the atomic and cavity detunings Δ and ϕ (or θ) [1]. This experiment is the closest realization of the standard single-mode theoretical model of optical bistability [2] and allows us to make absolute comparisons with theory [1,3]. For example, in Fig. 1 the measured extent (in incident intensity) of the bistable region is seen to agree quite well with the theoretical prediction. During the last year we have extended our study of the steady-state characteristics of optical bistability to the case of nonzero detunings (dispersive case). This gives us a very rich parameter space to be explored; work has been done in that direction with encouraging results [4]. One such is shown in Fig. 2.

Our resonator, which can be used in either a standing-wave or a traveling-wave (ring) configuration, has proved to exhibit far more complex behavior in the absence of the nonlinear atomic medium than was originally thought. This fact, and also the fact that different modes of the resonator can have the same frequency, have led us to perform the experiment in standing-wave resonators which can be set in either the single-mode or mode-degenerate configuration. Our main previous experiments [1] were done in a mode-degenerate ring resonator and the results compared to the single-mode theory. There is great interest in verifying the validity of the single-mode theory, since it is the simplest realistic case which is tractable analytically [5]. Our results for absorptive (no detuning) bistability in the standing-wave resonators suggest that the single-mode theory may be an oversimplification. In the single-mode resonator, our results agree with the theory to within 5%, while the mode-degenerate case shows a 15% increase in the power necessary to switch to the high-transmission branch of the hysteresis curve. Furthermore, allowing nonzero detunings, we saw beam reshaping which gave rise to unexpected structure in the transmitted light, but only in the mode-degenerate case. Our analysis of these results is continuing.

Since our system is driven far from thermodynamic equilibrium, one suspects that other dynamical states can be found [6]. Armed with the results of the linear stability analysis [7] of the model which agrees with our results in the steady-state case, we explored parameter space in a search for the predicted instability. We found, as predicted, deep and sustained oscillations in the output intensity at frequencies between 20 and 100 MHz [8]; one area of parameter space which we explored is shown in Fig. 3. The observed instability is unique in many senses: it involves only a passive resonator and a saturable absorber, its physics is clearly explained from first principles, and there is no external feedback. As such, it provides a unique ground for study of the development of higher dynamical states. The instability has been observed in the ring resonator and both single-mode and mode-degenerate standing-wave resonators. To enhance

the probability of observation of higher dynamical states, we will make use of results reported here last year and increase the density of our two-level atoms by optical pumping. Using two lasers we can transfer population from the unused (F=1) ground state of sodium into the one (F=2) of interest to us. The resulting factor of 1.6 increase in density will, we hope, allow us to reach regions of parameter space in which effects such as period doubling and chaos are predicted to occur.

Another nonliner optical interaction in which theoretical analysis predicts interesting nonlinear dynamics such as period doubling to chaos is that of second harmonic generation in a resonant cavity [9,10]. In this interaction, a cavity resonant at a fundamental frequency ω_1 and at the second harmonic $\omega_2 = 2\omega_1$ is driven by a coherent pump at ω_1 or ω_2 while a frequency-doubling crystal converts ω_1 to ω_2 (and vice versa) within the cavity. Although conceptually simple, the experiment has not been performed as yet, one primary reason being the lack of a stable cw source of sufficient power in combination with a crystal of high enough conversion efficiency at the pump wavelength.

Based on a survey of various options, we selected the wavelength of 1.06 μm but since no known existing Nd:YAG lasers met our requirements [11-14], we decided to design our own YAG laser capable of providing about 3 W cw power with submegahertz frequency stability. Such stability is very difficult to obtain for high lamp powers due to thermal loading of the YAG rod. By employing a design that greatly reduces cavity sensitivity to thermal instabilities in the laser rod and by using an invar ring resonator, we have successfully put into operation a cw YAG laser with a short-term stability of 120 kHz rms and long-term stability of 1 MHz for output powers up to 1.8 W [15]. An etalon selects a single longitudinal mode and unidirectional operation is enforced by a Faraday rotator. Active frequency stabilization is accomplished with a 5-cm confocal resonator and a lock-in amplifier, with the error signal applied to a mirror in the ring cavity. The laser output is monitored with a 30-cm confocal interferometer. It is expected that the performance of this laser can still be greatly improved by isolating the reference interferometer, adding further stabilization electronics, and using a better Faraday isolator.

Another major consideration which was previously overlooked in the theoretical analysis of the experiment, but which is essential to its success, is that the coupling constant κ between the ω_1 and ω_2 fields depends sensitively upon the cavity configuration. Although it is assumed constant in the theory, to obtain a constant optimum value of κ is by no means trivial experimentally, as many authors were aware in the early days of nonlinear optics [16,17].

In an attempt to demonstrate explicitly the dependence of κ on cavity geometry we have designed an experiment [18] in which the

phases of two incident fundamental beams and the generated second harmonic (SH) beam can be varied independently. Two non-collinear traveling- or standing-wave beams from a frequency-stabilized dye laser are used to generate either one or two coherent SH sources from a KDP crystal within a cavity resonant at the SH. By varying the relative phases of the fundamental beams or by altering the length of the SH cavity or its position relative to the fundamental beams and relative to the doubling crystal, the SH output can be varied between two extrema which differ by as much as a factor of 70.

One implication of this dependence of SH phase on the fundamental phases and the dependence of coupling coefficiency on the overlap of the generated SH wave with the cavity mode function is that the simple procedure of detuning a resonator by changing its length will in certain geometries change the coupling coefficient as well. Another consequence is that, for the case of a collinear doubly-resonant cavity, since the radiated SH wave lags the polarization wave by $\pi/2$, suitable dispersive elements must be introduced between the crystal and the two cavity mirrors to satisfy the boundary conditions of reflection at both frequencies. Work is in progress to provide the necessary dispersion.

The JSEP program has supported our electron diffraction work over many years [19-21]. This work is now supported by the NSF. We are now in the process of combining our quantum optics effort and the electron diffraction work with the aim to understand the structure and annealing of thin films of amorphous chalcogenide alloys $(As_xS_y)_n$ and $(As_xSe_y)_n$. Their structures in the films are studied extensively and several contradicting results prevent an unique set of final conclusions.

We are preparing our own facilities to get ready to study the vapors of these alloys at a variety of oven temperatures by electron diffraction; this will lead to the geometrical structure of the compounds and their compositions. In order to aid the electron diffraction analysis the Raman and IR spectra are needed. Our laser facility is presently modified to set up a multipass cell with a common focal point and a new oven is constructed to provide a second vaporization source to measure the spectra of the gases. In order to insure optimal sensitivity without loss of resolution, we are currently installing a triple monochromator and we will record the spectra with an optical multichannel analyzer (OMA). Whenever possible, maximal usage will be made of resonance Raman effects to gain sensitivity.

C. REFERENCES

1. A.T. Rosenberger, L.A. Orozco, and H.J. Kimble, Phys. Rev. A28, 2569 (1983).

2. P.D. Drummond, IEEE J. Quantum Electron. QE-17, 301 (1981).

3. H.J. Kimble, A.T. Rosenberger and P.D. Drummond, in Optical Bistability 2, edited by C.M. Bowden, H.M. Gibbs and S.L. McCall (Plenum, New York, 1984), p. 1.

4. A.T. Rosenberger, L.A. Orozco and H.J. Kimble, in Fluctuations and Sensitivity in Nonequilibrium Systems, edited by W. Horsthemke and D.K. Kondepudi (Springer-Verlag, Berlin), p. 62 (1984).

5. L.A. Lugiato, in Progress in Optics, vol. 21, edited by E. Wolf (North-Holland, Amsterdam), p. 71 (1984).

6. H. Haken, Synergetics (Springer-Verlag, Berlin) (1983).

7. L.A. Lugiato, R.J. Horowicz, G. Strini, and L.M. Narducci, Phys. Rev. A30, 1366 (1984).

8. L.A. Orozco, A.T. Rosenberger and H.J. Kimble, Phys. Rev. Lett. 53, 2547 (1984).

9. P.D. Drummond, K.J. McNeil and D.F. Walls, "Nonequilibrium Transitions in Sub/Second Harmonic Generation I. Semiclassical Theory", Optica Acta 27, 321 (1980); C.M. Savage and D.F. Walls, "Optical Chaos in Sub/Second Harmonic Generation", Optica Acta 30, 557 (1983).

10. P. Mandel and T. Erneaux, "Amplitude Self-Modulation of Intracavity Second Harmonic Generation," Optica Acta 29, 7 (1982).

11. H.G. Danielmeyer, IEEE J. Quantum Electron. QE-6, 101 (1970); H.G. Danielmeyer and W.N. Leibolt, Appl. Phys. 3, 193 (1974).

12. H. Gerhardt, V. Bodecker, and H. Welling, Z. Angew. Physik 31, 11 (1971).

13. B.K. Zhou, T.J. Kane and R.L. Byer, J. Opt. Soc. Am. B1, 438 (1984).

14. P.A. Andreev, A.A. Gusev, S.V. Kruzhalov, L.N. Pakhomov and V. Yu. Petrun'kin, Sov. Tech. Phys. Lett. 4, 137 (1978); P.A. Andreev, S.V. Kruzhalov, L.N. Pakhomov and V. Yu. Petrun'kin, Sov. Tech. Phys. Lett. 26, 134 (1981).

15. Kun-Chi Peng, Ling-An Wu, and H.J. Kimble, Appl. Opt. 24, 938 (1985).

16. R.H. Kingston and A.L. McWhorter, "Electromagnetic Mode Mixing in Nonlinear Media", Proc. IEEE 53, 4 (1965).

17. A. Ashkin, G.D. Boyd and J.M. Dziedzic, "Resonant Optical Second Harmonic Generation and Mixing," IEEE J. Quantum Electron. QE-2, 109 (1966).

18. Ling-An Wu and H.J. Kimble, J. Opt. Soc. Am. B, 2, 697 (1985).

19. D.A. Kohl, P. Pulay and M. Fink, Theo. Chem. 108, 149 (1984).

20. S. Xie, M. Fink and D.A. Kohl, J. Chem. Phys. 81, 1940 (1984).

21. N.S. Ketkar and M. Fink, J. Am. Chem. Soc. 107, 338 (1985).

22. M.F. Daniel, A.J. Leadbetter, A.C. Wright and R.N. Sinclair, JNCS 41, 127 (1979).

23. I. Hertel and W. Stoll, Adv. Atom. Mol. Phys. 13, 113 (1978).

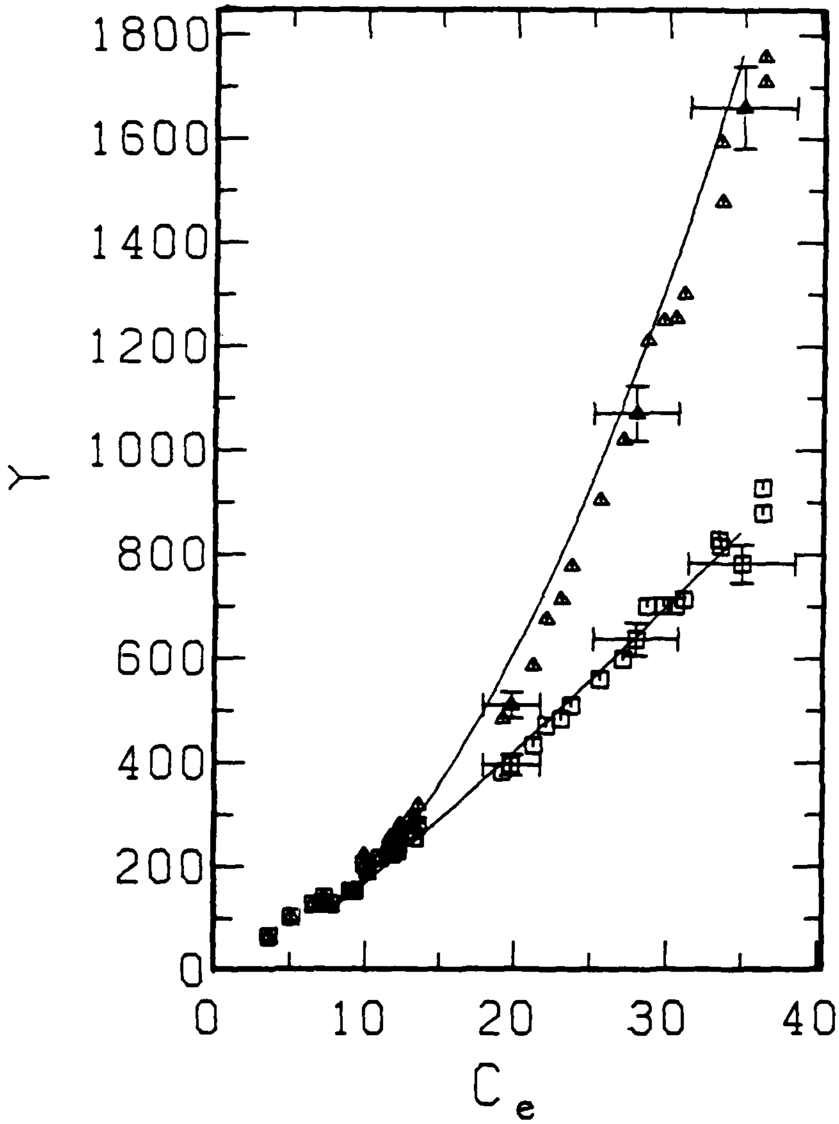

Fig. 1 Scaled incident switching powers Y vs. effective cooperativity C_e for zero atomic and cavity detunings. The points are measured values with relative uncertainties indicated; the curve is the theory from Ref. 2. No adjustment of theory or data has been made, but there are overall scale uncertainties for the data of $\pm$ 10% in C_e and $\pm$ 20% in Y.

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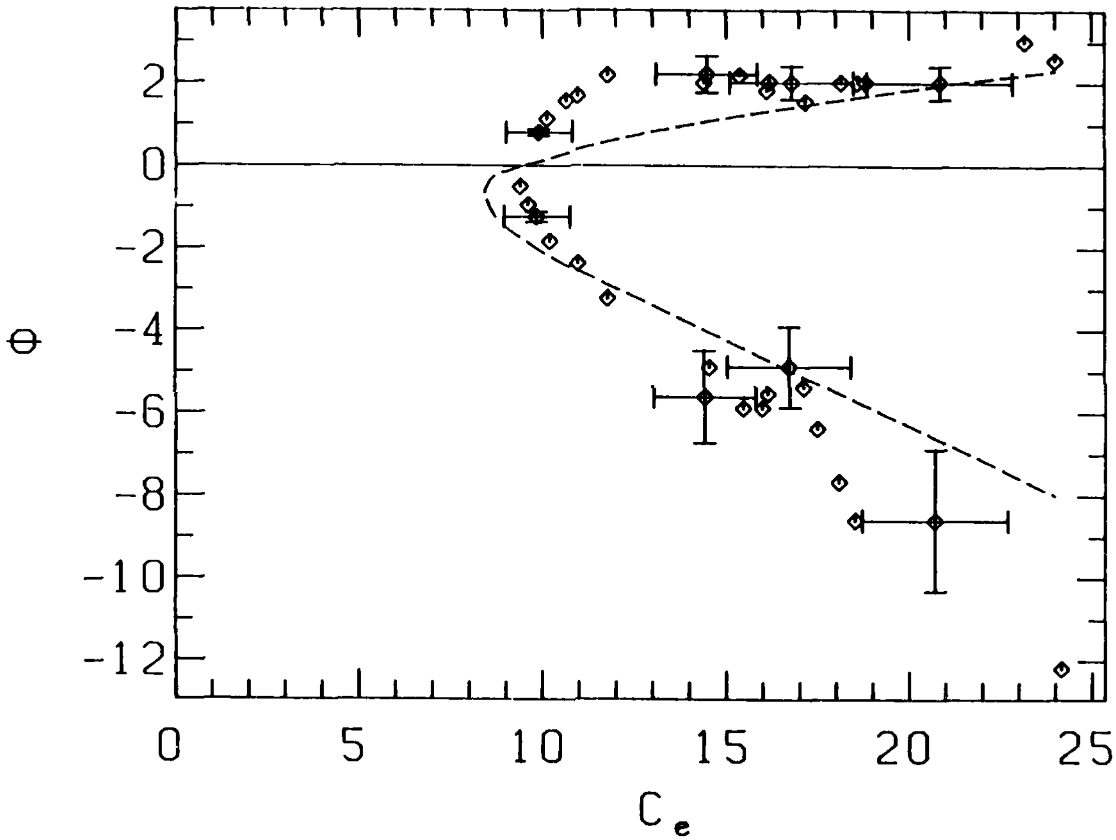

Fig. 2 Values of limiting cavity detuning ϕ at which bistability disappears vs. effective cooperativity C_e, for an atomic detuning of $\Delta = -0.75$. Errors indicated are relative; there are scale uncertainties of $\pm$ 10% in ϕ and C_e. The curve is from the theory of Ref. 2.

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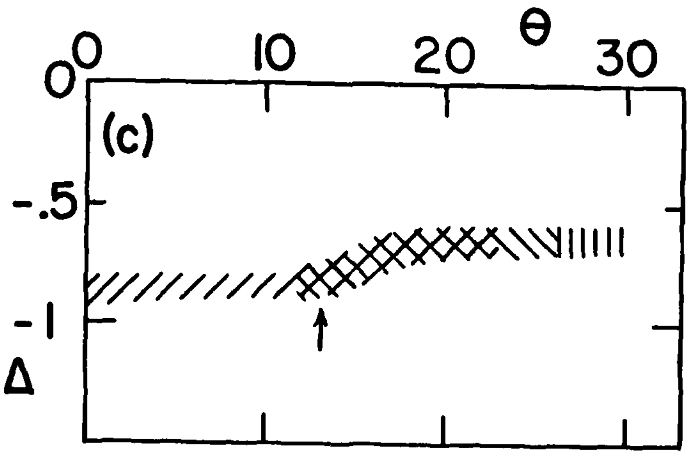

Fig. 3 Evolution of the instability as a function of cavity detuning ϕ for approximately constant atomic detuning Δ, $C \sim 155$, and $\gamma < 1.3 \times 10^5$ (///, bistability; \\\, instability; |||, no bistability, no instability).

IV. ELECTROMAGNETICS

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER, ELECTROMAGNETICS

Research Unit EM84-1 GUIDED WAVES IN COMPOSITE STRUCTURES

Principal Investigator: Professor T.Itoh (471-1072)

Research Associate: Yoshiro Fukuoka

Graduate Students: Nag Un Song and C.-K. Clive Tzuang

A. SCIENTIFIC OBJECTIVES: Several guided wave structures will be studied for potential applications in millimeter-wave configurations. Analysis procedures will be developed and design data obtained for structures that contain semiconductor materials. Some experimental verifications will be performed. The primary objective is to identify and characterize structures which may lead to new functional device configurations for millimeter-wave integrated circuits, particularly in monolithic form. The second objective is to provide analytical foundations for several guided wave structures being used in millimeter-wave circuits that have not been extensively analyzed.

B. PROGRESS:

(a) Finline Discontinuities

A number of works have been done for characterizing discontinuities in microstrip lines. The results of these works are important in the monolithic circuit design because it is almost impossible and very expensive to adjust the monolithic circuit after fabrication. However, in millimeter-wave monolithic circuits, guided wave structures other than microstrip lines are frequently used. To date only a few analyses have been performed on the discontinuities in slot lines, coplanar waveguides and finlines.

During the last reporting period, an efficient method for analyzing finline discontinuities has been developed. The method consists of computing the resonant frequencies of a resonator obtained by short circuiting a finline section containing the discontinuities to be analyzed. The computation of the resonant frequencies is based on a transverse resonance technique. The field is expanded in terms of LSM and LSE modes of the waveguide housing. After the slot field is expressed in terms of a suitable set of functions, we obtain a set of homogeneous equations, the solution to which provides the resonant frequency. From this information, the parameters of the equivalent circuit of the discontinuities are extracted as a function of frequency and geometry. The step discontinuity has been studied [1].

During this reporting period, cascaded finline step discontinuities have been analyzed. Although the transverse resonance method developed in the previous year can be directly applied to these structures, certain simplifications can be done if the structure is

longitudinally symmetric such as the cascaded step discontinuities that form capacitive strips or inductive notches. It is possible to introduce a magnetic wall at the midpoint between the two steps and consider only one half of the structure. Once the structure is analyzed electromagnetically, it is described in terms of network parameters. Figure 1 shows the results of a capacitive step consisting of two cascaded step discontinuities in a finline. The characteristics are given in terms of the element values of an equivalent T-junction at 26GHz [2].

(b) Distributed Phase Shifters

The slow wave phenomena discovered by a number of researchers [3] have good potentials for applications in distributed electronic phase shifters suitable in monolithic circuit configurations. The major concern in using such a structure is the insertion loss inherently associated with the lossy semiconductor included in the structure. This slow wave phenomenon can be observed both in MIS and Schottky-contacted microstrip and coplanar waveguides.

Two analytical methods have been developed for analyzing these structures. Results by both methods correlate very well with each other as well as with measured data [4]. Since the analysis methods have been developed, they can be used for various purposes such as design and optimization.

An attempt has been made to reduce the insertion loss and at the same time to enhance the slow wave factor [5]. We studied a coplanar waveguide on a periodically doped semiconductor substrate. Reduction of the loss and enhanced slow wave factor at higher frequencies have been predicted. The latter is caused by the existence of the surface wave stopband created by the periodicity.

The most interesting application of the slow wave effect in the foreseeable future is the development of an electronically variable distributed phase shifter. The electronic phase variation can be effected by changing the DC bias applied between the center and outer conductors of a coplanar waveguide with a Schottky-contacted center strip as shown in Fig. 2. This is because the size of the depletion layer can be adjusted by the DC bias, resulting in electronic control of the phase delay. For high frequency operation of such a device, it is important to reduce the attenuation caused by the semiconductor substrate. The method developed in the course of work described above has been applied to find the optimum conditions for both uniform and periodic Schottky contact coplanar waveguides as variable phase shifters. First, the optimum conductivity and the depletion layer thickness have been found for the electrode structures that do not cause breakdown for an appropriate bias and also do not increase the conductor loss excessively.

In actual phase shifter applications, it is more important to reduce the bias dependence of the insertion loss rather than the minimum insertion loss. The latter can be compensated for by an amplifier. The bias dependence, on the other hand, cannot easily be compensated for. For example, in the structure with a half micron center electrode and one micron gaps on a 3 μm doped region to be operated at 60GHz, the conductivity should be chosen at 10^5 s/m to minimize the bias dependence. The minimum insertion loss is obtained at a somewhat smaller value of conductivity.

For higher frequency operations, the conductor thickness cannot be neglected. An analysis method has been developed for a show-wave coplanar waveguide with finite conductor thickness. The method is based on the mode matching technique. By an appropriate elimination process of the unknown coefficients, a coupled matrix equation corresponding to the Fredholm integral equation of the second kind has been derived. This formulation makes the numerical solutions stable and fast converging [6].

(c) Periodic IMPATT Oscillator

Instead of a traveling wave IMPATT described in an earlier report [7], several lumped IMPATT diodes placed periodically in a transmission line can be used as a distributed oscillator if the structure is appropriately terminated. Figure 3 shows a schematic of the structure to be built in an integrated manner with printed transmission line. The diodes are formed on the ground plane. Metal posts connect the diode anodes to the microstrip. We calculated the RF admittance of the diodes, characterized the metal posts, and found the propagation constants and the characteristic impedance of the transmission line. From these results, the structure is modeled by a transmission line loaded periodically with impedances with negative real parts. Due to the periodicity only at a certain frequency for which the imaginary part of the signal impedance is zero does the structure oscillate. An example is worked out assuming that four diodes are placed at each 10 mils in a microstrip line with 10 mil wide and 50 mil long strip. The structure oscillates at 50 GHz [8].

(d) Finite Element Analysis of 3-Terminal Devices

A two-dimensional finite element (FEM) characterization has been applied to a realistic three terminal device such as GaAs FET's. For the first time, very stable solutions have been obtained with the FEM for GaAs FET's with carrier concentration higher than 10^{17} $1/cm^3$. The V-I characteristics have been obtained that compare reasonably well with experimental data. In the program, a temperature model is included so that the effect of the energy transport phenomena is better represented [9].

C. FOLLOW-UP STATEMENT: A number of topics reported above need to be extended for further study. The convergence of the finline discontinuities need to be accelerated by use of different basis functions incorporating edge conditions. In the area of distributed phase shifters, the conductor loss need to be calculated which is believed significant at millimeter-wave frequencies. In the area of IMPATT's, a model experiment is planned with packaged IMPATT's in the absence of published data. The finite element analysis work will be continued with more emphasis on characterizations of such phenomena as velocity overshoot. Applications to FET's with graded doping are also planned.

D. REFERENCES

1. R. Sorrentino and T. Itoh, "Transverse Resonance Analysis of Finline Discontinuities," 1984 IEEE MTT-S International Symposium, San Francisco, CA. (May 30-June 1, 1984).

2. R. Sorrentino and T. Itoh, "Transverse Resonance Analysis of Finline Discontinuities," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-30, No. 12, pp. 1633-1638 (December 1984).

3. H. Hasegawa, "Properties of Microstrip Line on Si-SiO_2 System," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-19, pp. 869-881 (November 1971).

4. Y. Fukuoka, Y.C. Shih and T. Itoh, "Analysis of Slow-Wave Coplanar Waveguide for Monolithic Integrated Circuits," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-31, No. 7, pp. 567-573 (July 1983).

5. Y. Fukuoka and T. Itoh, "Coplanar Schottky Variable Phase Shifter Constructed on GaAs Substrate for Millimeter-Wave Applications," Int. J. Infrared and Millimeter Waves, Vol. 5, No. 6, pp. 793-801 (June 1984).

6. C. Tzuang and T. Itoh, "Analysis of Coplanar Waveguide with Finite Conductor Thickness and a Substrate with a Lossy Layer," 1985 North American Radio Science/IEEE Ap-S Symposium Digest, Vancouver, British Columbia (June 17-21, 1985).

7. Y. Fukuoka and T. Itoh, "Field Analysis of a Millimeter-Wave GaAs Double-Drift IMPATT Diode in the Traveling-Wave Mode," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-33, No. 3, pp. 216-222 (March 1985).

8. Y. Fukuoka and T. Itoh, to be published.

9. N.U. Song and T. Itoh, "Accurate Simulation of MESFET by Finite Element Method Including Energy Transport and Substrate Effects," submitted to the 15th European Microwave Conference, Paris, France (September 1985).

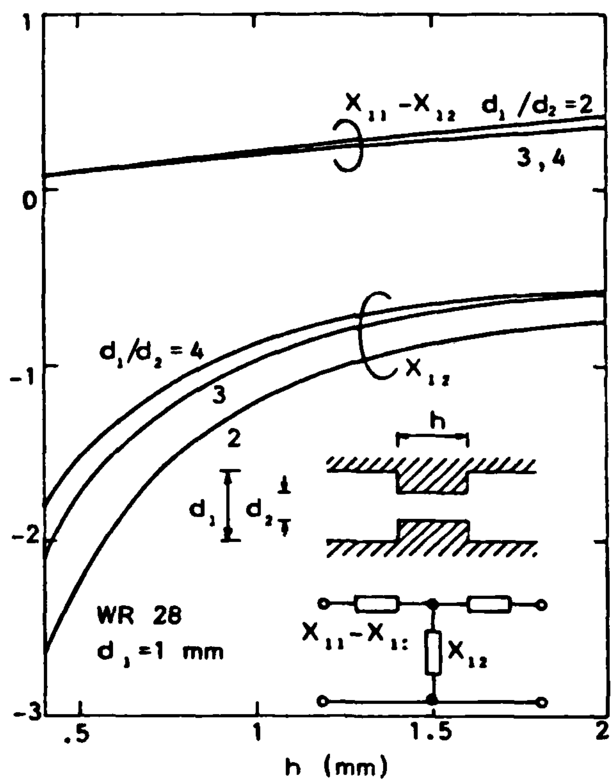

Figure 1 Characteristics of a Capacitive Step in a Finline.

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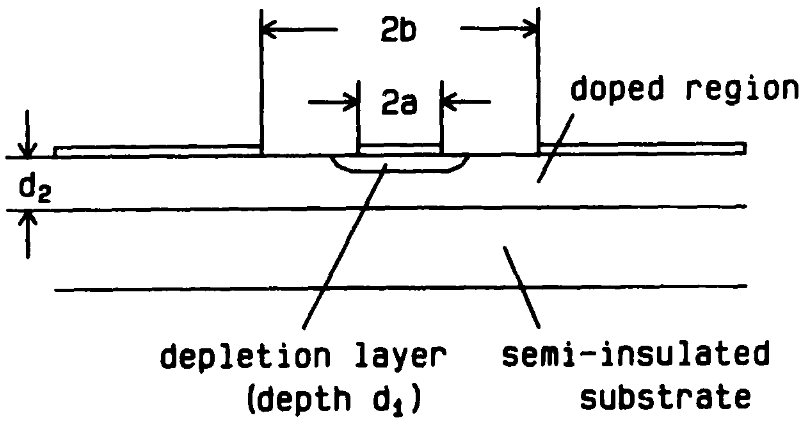

Figure 2 Distributed Phase Shifter.

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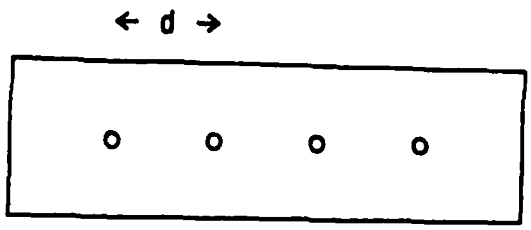

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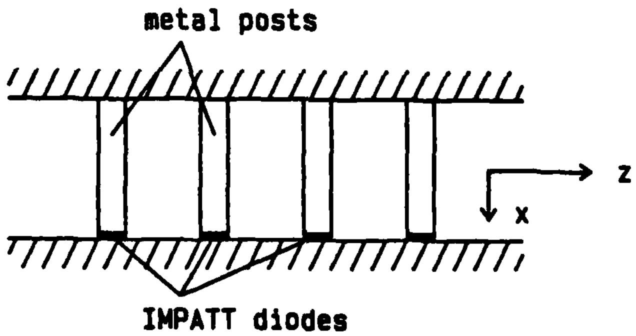

b

Figure 3 (a) Top view of the periodic IMPATT oscillator

(b) Side view

RESEARCH GRANTS AND CONTRACTS

RESEARCH GRANTS

FEDERAL FUNDS

Defense Advanced Research Projects Agency, Contract F33657-84-C-2058, "Research on Advanced Thin Film Magnetodielectrics," Professor R.M. Walser, Principal Investigator, October 31, 1983-November 1, 1986.

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National Science Foundation, DMR-8312013, "Texas/Cornell Synchrotron Beam Line Project," Professor J.L. Erskine, Principal Investigator, May 15, 1983-May 14, 1985.

National Science Foundation, ECS-8111616, "Investigation of Excess ("1/f") Noise and Dielectric Response of Non-Crystalline Structures Preceeding First Nucleation in Thin Film Systems," Professor R.W. Bene', Principal Investigator, November 15, 1981-April 30, 1985.

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National Science Foundation, ECS 8 802-1511, "Computational Models for Processing Sequences of Bioengineering Images," Professor J.K. Aggarwal, Principal Investigator, May 1, 1981-October 31, 1984.

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National Science Foundation, ECS-830-5340, Equipment for Digital Analysis in Stereo-scopic Light Microscopy, Professors J.K. Aggarwal and Ken Diller, Co-Principal Investigators, August 1, 1983-January 31, 1985.

National Science Foundation, "Optimal periodic Control Processes," Professor J.L. Speyer, Principal Investigator, January 15, 1985-June 30, 1988.

National Science Foundation, PHY-8211194, "Cooperant Atomic Activity in Optical Bistability (Physics)," Professor H.J. Kimble, Principal Investigator, January 1, 1983-June 30, 1986.

National Science Foundation, PHY-8351074, "Quantum Dynamics of a Bistable Absorber," Professor H.J. Kimble, Principal Investigator, August 1, 1985, continuing.

National Science Foundation, MEA 8211205, "Experiments on Spectral Energy Redistribution Due To Nonlinear Interactions and Phase and Amplitude Modulations During Transition to Turbulence," Professors E.J. Powers and R.W. Miksad, Co-Principal Investigators, February 15, 1983-February 15, 1986.

National Science Foundation, ECS-8412100, "Stochastic Adaptive Estimation and Control, " Professor S.I. Marcus, Principal Investigator, October 1, 1984-March 31, 1986.

Office of Naval Research, Contract N00014-79-C-0533, Mod P00007, "MMW Transmission Lines," Professor T. Itoh, Principal Investigator, September 1, 1984-August 31, 1985.

Office of Naval Research, Contract N000014-79-C-0533, "Studies of Non-Reciprocal Effects in Planar Submillimeter to Optical Waveguiding Structures," Professor T. Itoh, Principal Investigator, June 1, 1980-August 31, 1984.

Office of Naval Research, Contract N000114-84-K-0453, "Study of Electromagnetic Interactions in Microstructural TFM Particles and Ensembles," Professor R.M. Walser, Principal Investigator, June 1, 1984-March 31, 1985.

United States Air Force Armament Lab, Eglin AFB, Florida, "Investigation of Information Enhancement, Estimation, and Guidance Algorithms for Homing Missiles," Professor J.L. Speyer, Principal Investigator, October 1, 1981-September 30, 1984.

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United States Air Force Office of Scientific Research Grant No. AFOSR 84-0089, "Research in Adaptive and Decentralized Stochastic Control," Professor S.I. Marcus, Principal Investigator, March 15, 1984-November 14, 1985.

United States Air Force Office of Scientific Research /SCEEE, Professor M.F. Becker, Principal Investigator, February 1, 1984-December 1, 1984.

United States Air Force Office of Scientific Research , AFOSR 83-0131, "High Resolution Electron Energy Loss Studies," Professor J.L. Erskine, April 1, 1983-March 31, 1986.

United States Air Force Office of Scientific Research, F49620-83-K-0013, "Automatic Recognition and Tracking of Objects," Professor J.K. Aggarwal, Principal Investigator, December 1, 1982-December 31, 1984.

United States Air Force Office of Scientific Research/RADC, "Studies of Electrical Activation and Impurity Migration in Ion-Implanted Indium Phosphide," Professor B.G. Streetman, Principal Investigator, February 1984-March 1985.

United States Air Force Office of Scientific Research, F49620-85-K-0007, "Automatic Recognition and Tracking of Objects," Professor J.K. Aggarwal, Principal Investigator, January 1, 1985-December 31, 1985.

United States Air Force Office of Scientific Research, "Guidance Algorithms for Homing Missiles with Bearings-Only Measurement," Professor J.L. Speyer, Principal Investigator, September 30, 1984-September 29, 1985.

United States Air Force School of Aerospace Medicine, Contract F33615-83-K-0610, "Solid State Electronic Gas Sensors," Professors J.W. Barlow, D.W. Lloyd and R.M. Walser, Co-Principal Investigators, September 1, 1982-October 31, 1984.

United States Army Research Office, DAAG29-81-K-0053, "Interface Structures for Millimeter-Wave Circuits," (additional funding), Professor T. Itoh, Principal Investigator, March 1, 1981-August 31, 1984.

United States Army Research Office, DAAG29-84-K-0076, "Guided Wave Interactions in Millimeterwave Integrated Circuits," Professor T. Itoh, Principal Investigator, September 1, 1984-August 31, 1987.

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General Dynamics, "Development of Synthesis Techniques For Tolerant Digital Flight Control Systems," Professor J.L. Speyer, Principal Investigator, February 17, 1984-June 1, 1985.

Hughes Aircraft Company, P.O.#P3-100001-U24, "Printed Line Structures for Monolithic Millimeter-Wave Circuits," Professor T. Itoh, Principal Investigator, May 15, 1984-September 30, 1985.

Texas Atomic Energy Research Foundation Grant, "Analysis and Interruption of Plasma Fluctuation Data Utilizing Digital Time Series Analysis," Professor Edward J. Powers, Principal Investigator, May 1, 1984-April 30, 1985.

Texas Instruments, "Millimeter-Wave Transmission Lines Study," Professor T. Itoh, Principal Investigator, June 1, 1979-December 31, 1984.

Venture Research Unit of British Petroleum, Int., "Nonequilibrium Phase Transitions in Optical Systems," Professor H.J. Kimble, Principal Investigator, February 1, 1983-January 31, 1986.

Robert A. Welch Foundation, F534, "Electron Scattering from Alkali Halide Vapors," Professor M. Fink, Principal Investigator, June 1982-May 31, 1985.

Robert A. Welch Foundation, "Coherent Raman Spectroscopy of Molecular Ions", Professor J.W. Keto, Principal Investigator, June 1, 1984-May 31, 1985.

CONSULTATIVE AND ADVISORY FUNCTIONS

Professor M.F. Becker spent the summer as a visiting scientist at the Air Force Weapons Laboratory working with Drs. A.H. Guenther and A.F. Stewart and Lt. J.A. Kardach investigating the relation between laser damage and changes in surface potential.

Professor M.F. Becker has consulted several times (at the Boulder Laser Damage Conference, at the Southwest Conference on Optics, and by telephone) with Dr. Hugh Hurt of the Naval Weapons Laboratory about metal surface finishing methods.

In November 1984, Dr. John Keto visited the Laser Division at Sandia National Laboratories upon invitation by Dr. Adelbert Owyoung who has developed high precision CW Raman gain spectroscopy.

Professor Ben Streetman serves on the National Research Council panel for evaluation of proposals submitted to the Army Research Office. He also serves on the Engineering Research Council Panel on Materials Systems Research. His technical interactions with DoD laboratories include sharing of InP samples and data with Eirug Davies of RADC (Hanscom AFB) and Harry Dietrich of NRL.

T. Itoh visited the Army Electronics Technology and Devices Laboratory, Fort Monmouth to discuss millimeter-wave structures with Drs. Wandinger, Babit and Stern on May 3, 1984.

T. Itoh visited Dr. G. Simmons and gave a seminar on millimeter-wave transmission lines at Army Harry Diamond Laboratory on June 29, 1984.

T. Itoh participated and gave a keynote speech at ARO Workshop on Near Millimeter Wave Communication technology organized by Drs. J.W. Mink and F. Schwering, December 5-8, 1984, at New York Institute of Technology, Glenn Cove, N.Y.

Edward J. Powers visited Dr. Robert Whitehead and Dr. Michael Reischmann of ONR on April 4-5, 1984 to discuss research on turbulence and turbulence modification.

In February 1985, E.J. Powers presented the seminar "Applications of Digital Time Series Analysis Techniques" at the U.S. Air Force Rocket Propulsion Laboratory, Edwards A.F.B. He also discussed with Dr. T. Park and J. Levine digital signal processing problems relating to the analysis and interpretation of fluctuation data associated with instabilities which occur in solid propellant rocket engines. E.J. Powers also provided Dr. Park a copy of a bispectral analysis program.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear detection and estimation, (2) electronic time-variant signal processing, and (3) digital time series analysis with applications to nonlinear wave phenomena.

In the Solid State Electronics area recent findings in (1) solid state interface reactions and instabilities, (2) electronic properties and structure

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of metal silicides and interfaces, and (3) implantation and interface properties of InP and related compounds are described.

In the Quantum Electronics area progress is presented for the following projects: (1) quantum effects in laser induced damage, (2) nonlinear Raman scattering from molecular ions and (3) nonlinear optical interactions.

In the Electromagnetics area progress in guided waves in composite structures is summarized.

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